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ASSESSMENT OF CARGO SPACE SEATING PERFORMANCE APPLICABLE TO PAVE HAWK AND BLACK HAWK AIRCRAFT DURING HELICOPTER MISHAPS

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Interim Report

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14. ABSTRACT

A series of dynamic tests of both operational and prototype H-60 troop seats was performed to determine occupant protection during a crash event. The H-60A/L, UH-60M, prototype Glatz, and prototype Wolf seats were tested at several impact orientations including Combined Vertical, Pure Vertical and Combined Horizontal, and at different acceleration and energy levels using small female and large male manikins. Biodynamic data were compared to injury criteria recommended by the Army Full Spectrum Crashworthiness (FSC) Report (2011). Data were also compared to Eiband and operational mishap data. The testing and data analysis methodology developed during the program can be used to baseline and compare seats within a given aircraft platform or across different aircraft platforms. Combining quantitative injury criteria measures, such as those outlined within the FSC, along with laboratory and operational mishap data, demonstrate that new seats and seat technology can be quickly and inexpensively tested either singly or in a comparative evaluation, independent of aircraft platforms.

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H-60, troop seats, Wolf Technical, Glatz Aeronautical, H-60A/L, UH-60M, crashworthiness, crashworthy

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This program was conducted by the Biodynamics and Response Team of the Applied Neuroscience Branch of the Human Effectiveness Directorate (711HPW/RHCP), under Workunit 71840223. Test support was provided by Infoscitex Corp. (IST) under contract FA8650-09-D-6949.

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EXECUTIVE SUMMARY

A series of dynamic tests of both operational and prototype H-60 troop seats was performed to define and compare occupant protection during a crash event. The H-60A/L, UH-60M, prototype Glatz, and prototype Wolf seats were tested at several impact orientations including Combined Vertical, Pure Vertical and Combined Horizontal, and at different acceleration and energy levels using small female and large male manikins. Acceleration, force, and moment data collected using the manikins were compared to standard injury criteria established by the Full Spectrum Crashworthiness Report. The currently used H-60A/L aft-facing seat demonstrated the highest level of protection among the seats at the impact levels tested when comparing manikin response to the injury criteria used for the study. The UH-60M seat demonstrated more consistent structural strength compared to the H-60A/L and prototype seats. Both the Glatz and Wolf seats resulted in structural failures that will require further redesign of the seats, though both show promise with regards to occupant protection during a crash event. All seats generated seat pan accelerations within the "Area of Moderate Injury" when using the Eiband criteria. All seats performed well compared to established injury criteria when using with a large occupant; however, all seats showed deficiencies when compared to the criteria using a small occupant.

Relative comparison of the crashworthiness of the seats was made to the legacy H-60A/L seat with use of available operational mishap data. The legacy H-60A/L seat generally performed better than the UH-60M, Glatz, and Wolf seats with respect to peak lumbar z-axis force and resultant chest acceleration. However, the same types and magnitudes of major and fatal injuries are anticipated with any of the seats tested.

Seat structural strength was a metric that showed the most distinguishable variance between seats from a comparison stand-point. The UH-60M was shown to be the strongest seat tested during the program. It is anticipated that head and other impact injuries shown in the operational mishap data will be mitigated if a seat stays attached to the aircraft and the occupant is not detached within the cabin, although the level of mitigation is unknown.

The testing and data analysis methodology developed during the program can be used to baseline and compare seats within a given aircraft platform or across different aircraft platforms. Combining quantitative injury criteria measures, such as those outlined within the Army's Full Spectrum Crashworthiness (FSC) criteria, along with laboratory and operational mishap data, allows new seats and seat technology to be quickly and inexpensively tested and compared. Additionally, injury potential as the seat strokes during a crash event can be compared across multiple aircraft and rotorcraft platforms independent of the aircraft structure. However, testing of seats within specific aircraft platforms is still necessary as additional injury mechanisms such as impact injury can be explored.

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1.0 INTRODUCTION

A recent study of 917 Class A and B Department of Defense (DoD) helicopter mishaps indicated that occupants of helicopter cargo compartments have a significantly greater chance of being injured or killed during a mishap than occupants in the cockpit (Mapes et al, 2007). The study discovered that vascular injuries to the chest were the leading cause of fatality in Class A helicopter mishaps and that open skull fractures were the second. These two mechanisms of fatality were the most common compared to other causes such as injuries to the neck and the extremities. The study also indicated that Navy SH-60B/F/H aircraft had a lower rate of cargo compartment injury and death, particularly from 1995 through 2005, when compared with other DoD helicopters from 1985 through 1994. This may have been due, in part, to the aircraft being originally outfitted with stroking, crashworthy seating. A finding from the Rotorcraft Survivability Study (2009) discovered that of 496 rotorcraft fatalities from October 2001 through September 2009, over 90% of those fatalities occurred during the crash event.

Based on these reports, the Neuroscience Branch (711 HPW/RHCP) agreed to conduct a dynamic comparative test program of currently-fielded and prototype troop seating for the H-60 Black Hawk and Pave Hawk rotorcraft. The test program consisted of impact testing of stock UH-60A/L, UH-60M seats, and prototype seats from Glatz Aeronautical (Newtown, PA) and Wolf Technical Services (Indianapolis, IN). The tests were conducted to compare how effectively the seats protected occupants ranging from the 5th percentile female to 98th percentile male. A series of ten tests using each type of seat was performed. Test orientations, manikins, and impact levels were based on MIL-S-85510(AS) as well as the impact levels at which currently-fielded H-60 troop seats were accepted for operational use.

Testing was conducted under a Memorandum of Agreement (MOA) with the Defense Safety Oversight Council (DSOC) and the Office of the Secretary of Defense, Deputy Director, Live Fire Test & Evaluation (OSD/DOT&E).

The comparative testing is experimental and not intended to qualify specific seats for acquisition. Consideration of the weight and cost of seats were beyond the scope of this research effort. Test conditions were chosen to show crashworthiness protection at different levels and orientations. The methodology that was developed for this effort allows seating to be tested independent of airframes and could be used for the basis of performance testing prior to acquisition decisions being finalized. Comparative testing that is not dependent upon specific airframes allows direct comparison of the crashworthy properties of various seats developed at different times and with different technologies. Seating between different aircraft can be directly compared, and structural and energy attenuator technologies can be identified and shared among rotorcraft and fixed-wing platforms using the defined test methodology.

This testing focuses solely on the survivability of the seat and occupant biodynamics during primary impact. Secondary injury effects such as an occupant impacting other occupants, equipment, or aircraft structure are not considered in this study. Also, the ability of the occupant to egress the rotorcraft post-crash was not considered.

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2.0 METHODS

2.1 Summary of Technical Approach

A series of short-duration impact acceleration tests were conducted with a Lightest Occupant In Service (LOIS) manikin representing a 5th percentile female and a Large Anthropomorphic Research Device (LARD) manikin representing a 98th percentile male. Both LOIS and LARD manikins are Hybrid III–type manikins that have been scaled to represent small and large occupants in the aerospace environment. The impact acceleration inputs to the seats were generated using the Horizontal Impulse Accelerator (HIA) and Vertical Deceleration Tower (VDT). The experimental conditions varied in seat orientation with fixed impact amplitudes and durations.

Measurements included sled and carriage accelerations and velocity, seat accelerations, and manikin head, lumbar, and torso accelerations, forces, and moments. A test fixture was designed and fabricated to mount the seats in various orientations during impact and was instrumented with load cells at all seat mounting points.

2.2 Test Matrix

Figure 1 shows the coordinate system used to set up seat orientations as well as data channels. The "right-handed" coordinate system is used.

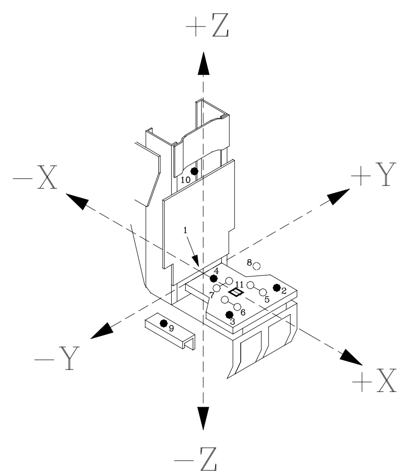

Figure 1. Coordinate system

The troop seats were tested in three different orientations.

(1) Combined Vertical (CV) – For the forward-facing seat, the seat was pitched 30 degrees forward, with a 10 degree roll relative to the positive z-axis acceleration pulse. For the aft-facing seat, the seat was pitched 30 degrees aft with a 10 degree roll relative to the acceleration pulse. Orientations are shown in Figure 2.

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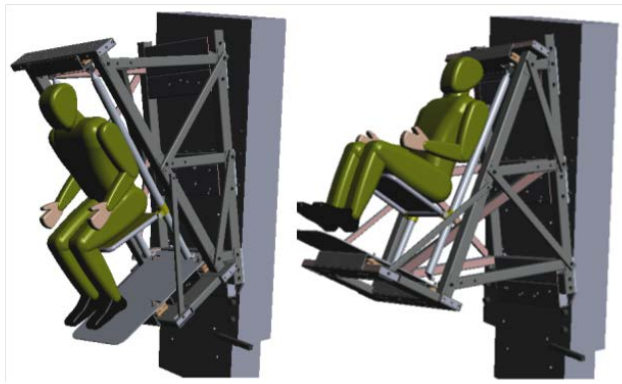

Figure 2. Combined Vertical (forward, aft)

(2) Combined Horizontal (CH) – For the forward-facing seat, the seat was yawed 30 degrees relative to the x-axis acceleration pulse. For the aft-facing seat, the seat was yawed 150 degrees relative to the acceleration pulse. Orientations are shown in Figure 3.

Figure 3. Combined Horizontal (forward, aft)

(3) Pure Vertical (PV) – The seats has no offset relative to the positive z-axis acceleration pulse. The orientation is shown in Figure 4.

Figure 4. Pure Vertical

Testing configurations were based on MIL-S-85510(AS) and previous testing of the legacy H-60A/L troop seat (Sikorsky Document SER-70102). It should be noted that the rise times for the

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CV and PV tests are roughly half of what is required to meet MIL-S-85510(AS). The experimental test matrix is summarized in Table 1.

Table 1. Test Matrix

Cell	Orientation	Acceleration (G)	Delta V (ft/s)	Rise Time (ms)	Manikin
A	CV	23	39	30	LOIS
B	CV	35	48	26	LOIS
C	CV	25	40	30	LARD
D	CV	36	48	25	LARD
E	CH	18	46	78	LARD
F	CH	24	53	62	LARD
G	PV	16	32	35	LOIS
H	PV	34	46	26	LOIS
I	PV	16	31	35	LARD
J	PV	35	47	26	LARD

2.3 Facilities and Equipment

The 711HPW/RHCP HIA was used for all Combined Horizontal testing. The HIA consists of a 4 ft by 8 ft sled positioned on a 204 ft track and is accelerated using a 24-inch diameter pneumatic actuator. The HIA operates on the principle of differential gas pressures acting on both surfaces of a thrust piston in a closed cylinder. The impact acceleration occurs at the beginning of the experiment as stored high-pressure air is allowed to impinge the surface of the thrust piston, thus propelling the sled. As the sled breaks contact with the thrust piston, the sled coasts to a stop or is stopped with a triggered pneumatic brake system. The impact acceleration is roughly sinusoidal. Metering pin 52 was used for all cells.

The 711HPW/RHCP VDT was used for all Combined Vertical and Pure Vertical tests. The VDT is a 40 ft gravity-assisted tower primarily used for simulation of the catapult phase of ejection. The VDT facility is composed of two vertical rails and a drop carriage. The carriage is allowed to enter a free-fall state that is guided by the rails from a pre-determined drop height. A plunger mounted on the rear of the carriage is guided into a cylinder filled with water located at the base and between the vertical rails. A deceleration pulse is produced when water is displaced from the cylinder by the carriage-mounted plunger. The pulse shape is also roughly sinusoidal and is controlled by varying the drop height, which determines the peak G-level, and by varying the shape of the plunger, which determines the rise time and duration of the pulse. Metering pin 104 was used for all cells.

MIL-S-85510(AS) requires deformation of the seat mount locations to simulate deformation of an airframe during a crash event. For these comparison tests, it was determined that deformation of mounting points was not necessary.

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2.4 Subjects

A LOIS manikin, representing a 5th percentile female (by weight and height), was used for testing. LOIS is a Hybrid III-variant manikin with a straight spine. LOIS is currently used by the Air Force and Joint Strike Fighter (JSF) during ejection seat sled testing. LOIS was dressed in a flight suit and a medium Advanced Combat Helmet (ACH) for a total weight of 107.2lbs. LOIS weight distribution is shown in Table 2.

Table 2. LOIS Manikin Weights

	Weight (lbs)
Upper torso	
Manikin	45.1
Instrumentation	1.7
Cables	1.6
Lower Torso	
Manikin w/abdomen	47.2
Instrumentation	1.6
Helmet, flight suit	10
Total	107.2

A LARD manikin, representing a 98th percentile male (by weight and height), was also used for testing. LARD is a Hybrid III-variant manikin with a straight spine. LARD is also used by the Air Force and JSF in ejection seat sled testing. LARD was dressed in a flight suit and a medium ACH helmet for a total weight of 247.1lbs. LARD weight distribution is shown in Table 3.

Table 3. LARD Manikin Weight

	Weight (lbs)
Upper torso	
Manikin	109
Instrumentation	1.7
Cables	1.6
Lower Torso	
Manikin w/abdomen	118.2
Instrumentation	1.6
Helmet, flight suit	15
Total	247.1

2.5 Seats

2.5.1 H-60A/L Seat

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The H-60A/L seat is the standard, legacy troop seat currently installed in Army, Navy, and Air Force H-60 rotorcraft. The seat consists of an aluminum tubing structure with a fabric covering for the seat pan and seat back (Figure 5). There are two attachment points at the top of the seat 10 inches apart and four attachment points at the bottom of the seat. The seat uses wire benders to provide energy attenuation during a crash event. The seat does not have side supports and includes a backpack "pouch" that is accessible through a Velcro seat back. For this program the backpack pouch was kept closed. Seats were obtained through multiple sources including the Defense Reutilization and Marketing Offices (DRMO), both AF and Navy maintenance depots, and private sellers. Seats were inspected and rebuilt as needed using AF TO 1H-60(H) G-2-2 and were restored to what would be acceptable for flight use.

Figure 5. H-60A/L Fore and Aft seats

2.5.2 UH-60M Seat

The UH-60M seat is currently being used in the Army UH-60M aircraft (Figure 6). The top seat mounts are the primary structural attachment to the rotorcraft. The legs of the seat only provide stability to the seat and do not support the seat structurally between the cabin floor and ceiling. The seat back of the UH-60M seat is fabric and includes side panels that attach to the sides of the seat pan. The seat pan is made of a rigid aluminum plate. All UH-60M seats were purchased new.

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Figure 6. UH-60M Troop Seat

2.5.3 Glatz Aeronautical Prototype Seat

The Glatz Aeronautical Prototype seat was partially developed under an Air Force Research Laboratory (AFRL) Phase I Small Business Innovative Research (SBIR) program. The seat delivered to AFRL for testing is called the "Next Generation Troop Seat (NGTS) Mrk5Mod1A". The seat was modified during testing with stronger seat floor mounts and additional structure for higher energy tests. The modified seat is called the NGTS Mrk5Mod1B. Both variants will be called the "Glatz seat" in this paper and any modifications to the seat are noted in the individual test notes. The seat is unconventional in that it has limited hard structure and consists of a large foam seat pan with fabric side supports (Figure 7). The seat hangs from H-60A/L seat supports and has 1-inch webbing to secure the seat structure to the floor. All seats were purchased new. The seat is in development and does not represent a finalized design.

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Figure 7. Glatz Aeronautical Prototype Seat

2.5.4 Wolf Technical Prototype Seat

The Wolf Technical Services prototype seat was developed through an Air Force Research Laboratory (AFRL) Phase II Small Business Innovative Research (SBIR) program. The seat configuration that was used for this program has a fabric seat pan and seat back with a friction brake as an energy attenuator (Figure 8). The brake is not engaged unless a certain acceleration level is obtained during a hard landing or crash event. The attenuator was designed to be reusable. The prototype seat was specifically manufactured to test how well the technology would protect an occupant during a crash event and does not represent a production-ready seat.

Figure 8. Wolf Technical Prototype Seat

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2.6 Data

Data were collected at 1,000 samples per second and filtered on-board the Data Acquisition System (DAS) using an 8-pole Butterworth filter at 120Hz. The filtering chosen has been demonstrated to be adequate for this type of comparison test program but is not necessarily consistent with filtering used during qualification testing. Table 4 lists the data channels collected. High-speed video of the test was taken at 1000 frames per second.

Table 4. Data Channels

Carriage X, Y, and Z Acceleration (G)
Seat Fixture X, Y, and Z Acceleration (G)
Seat Pan X, Y, and Z Acceleration (G)
Top Left Seat Mount X, Y, and Z Force (LB)
Top Right Seat Mount X, Y, and Z Force (LB)
Bottom Left Front Seat Mount X, Y, and Z Force (LB)
Bottom Right Front Seat Mount X, Y, and Z Force (LB)
Bottom Left Rear Seat Mount X, Y, and Z Force (LB)
Bottom Right Rear Seat Mount X, Y, and Z Force (LB)
Left Torso Restraint Force (LB)
Right Torso Restraint Force (LB)
Left Lap Restraint Force (LB)
Right Lap Restraint Force (LB)
Internal Head X, Y, and Z Acceleration (G)
Internal Head Y Angular Acceleration (Radians/Sec^2)
Internal Upper Neck X, Y, and Z Force (LB)
Internal Upper Neck Moment X, Y, and Z Torque (IN-LB)
Internal Lower Neck X, Y, and Z Force (LB)
Internal Lower Neck Moment X, Y, and Z (IN-LB)
Internal Chest X, Y, and Z Acceleration (G)
Internal Chest Y Angular Acceleration (RAD/SEC^2)
Internal Lumbar X, Y, and Z Acceleration (G)
Internal Lumbar X, Y, and Z Force (LB)
Internal Lumbar Moment X, Y, and Z Torque (IN-LB)

The seat pan accelerometers were placed in a protective ‘pancake” in the middle of the seat pan directly underneath the manikin. Two different “pancakes” were used – one made of plastic and one made of rubber. The Glatz seat CV orientation tests were performed with the seat pan accelerometers under the cushion. This variation was per the seat manufacturer’s instruction. After further consideration putting the accelerometers between the seat pan and manikin allowed for better comparison between seats. The PV and CH tests were conducted with the accelerometers between the manikin and top of the seat pan. Location of the seat pan accelerometers for the Glatz seat tests are noted in the individual test notes.

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2.7 Test Procedures

Data channels were zeroed prior to the manikin being placed into the seat. The manikin was then placed into the seat and restraint belts were pre-tensioned to 20lbs +/- 5lb when possible. Due to the design of some of the seats and sizes of the manikins, pre-tensioning to a specific force was not possible in all of the restraint belts. The helmet was placed on the manikin head and secured as tight as possible to prevent slippage. On the VDT the carriage was raised to a pre-determined height to provide the required acceleration and velocity profile and then dropped. On the HIA the cylinder was pumped up to pre-determined pressures to match the desired acceleration and velocity profile. Prior to the manikin being removed from the seat, the restraint buckle release loads were recorded.

2.8 Injury Criteria

The injury probability metrics used were primarily taken from the Full Spectrum Crashworthiness (FSC) report (Bolukbasi et al, 2011**)** as it incorporates the most recent recommended troop seating injury criteria for the head, neck, chest, lumbar spine, and extremities. Not all criteria from the FSC report were used as they were not applicable to the test setup. For instance the Head Injury Criterion (HIC) was not used because no aircraft structure was simulated during testing other than the single seat itself. Reporting of head-strike data could be misleading and irrelevant given the experimental setup for this test series.

For neck injury probability, Nij was used as it is the most accepted and validated criteria in the X-Z plane. Nij combines tension (t), compression (c), flexion (f), and extension (e) of the upper neck to determine a probability of injury at a given injury level and is part of the JSF Neck Injury Criteria (NIC) (Nichols 2006). Though primarily developed and used in automotive environments, Nij thresholds have been modified for military personnel in aircraft environments for different occupant sizes. A Nij value of 0.5 correlates to a 10% probability of an Abbreviated Injury Scale (AIS) >=2 neck injury. For instance a Ntf value of 0.5 is a 10% probability of an AIS >=2 neck injury in tension-flexion. Nte is is the Nij value in tension-extension, Ncf is compression-flexion, and Nce is compression-extension. Nij can be calculated for both upper and lower neck locations. Only upper neck Nij is reported for this program.

A limitation of Nij is that it was developed primarily for +/-X accelerations and does not report off-axis injury probability. The Upper Neck Moment Index X (UNMIx) and Upper Neck Moment Index Z (UNMIz) were developed by the Navy to look at off-axis neck injury probability (Nichols 2006). These criteria are part of the JSF NIC and use both linear force and neck moments, just like Nij, to determine a neck injury probability. As a guideline an UNMIx or UNMIz value of 0.5 correlates to a 10% probability of an AIS >=2 neck injury. Validation of the criteria has been limited; however, the UNMIx and UNMIz are reported in this study for comparison.

For chest injury both chest acceleration and belt forces were collected during testing. The FSC Report recommends restraint belt force for injury probability. The criteria states that for one torso belt, the peak force must be less than 1750 lb, and, for more than one torso restraint belt, the total peak force must be below 2000 lb. All seats tested during this program utilized 4-point restraints, thus the 2000 lb limit of the torso restraint belts is most applicable. For the majority of testing, all four belts (left and right torso straps, left and right lap belt) were instrumented. However, lap belt force cells were not used during all tests due to the manikin fit within the seat, design of the seat, or length of available belts to instrument.

A chest resultant acceleration limit of 60G (Mertz 1989) for manikins is discussed within the FSC, though the FSC does not recommend its use. The FSC recommends use of the torso belt peak loads instead. The reason for this is that the torso belt loads and the chest resultant acceleration criteria should show similar results in some orientations. For this study the chest resultant accelerations were used as thoracic organ injury is caused by acceleration and torso belt loading in the CV and PV orientations do not show significant differences between the seat restraints tested. Both torso belt restraint loads and chest acceleration are reported.

Lumbar injury probability is compared to limits derived by Desjardins (2008). The Desjardins lumbar force limits are based on 19.9 times the weight of a manikin above the lumbar load cell. For a standard LOIS manikin this correlates to a 933 lb compression limit. For a 95% percentile Hybrid III male this correlates to a 1757 lb compression limit. For the specific manikins used in this test program, the limits are 963 lbs for the LOIS (based on manikin and instrumentation weight above the lumbar load cell equal to 48.4 lbs) and 2235 lbs for the LARD (based on manikin and instrumentation weight above the lumbar load cell equal to 112.3 lbs).

Another criterion discussed but not recommended in the FSC to determine lumbar injury probability is the Dynamic Response Index (DRI). DRI was developed primarily for ejection seat lumbar injury probability and consists of a spring-damper model of the spine. DRI is not recommended in FSC as it is most useful for rigid, non-stroking seats with longer impact rise times and applicability to troop seats is questionable (Pellettiere 2011, Desjardins 2008). DRZ Dynamic Response Index in the vertical (Z) direction), is reported for the CV and PV orientations for comparison only.

A whole-body injury criteria discussed in the FSC is Eiband that was developed in the late 1950s. The Eiband criterion predates specific body-region injury criteria for seats (Eiband 1958). Based on a literature review, Eiband developed acceleration-duration curves for each body-axis providing a no injury/moderate injury/severe injury rating system. The limitation of this work is that a nominal trapezoidal pulse is used. Pulses from the VDT and HIA are nominally half-sinusoidal instead of trapezoidal, thus relevancy of the use of the Eiband criteria is questionable. The use of Eiband is also questionable given the 60+ years of specific body-region injury work that has been accomplished since the Eiband criteria was published. In some cases, more recently developed neck, chest, and lumbar criteria are inconsistent with the results of Eiband. Eiband is reported for the PV tests for comparison.

Figure 9 shows the definitions of the “Degree of Injury” given in the Eiband report. The ‘Moderate’ injury is one that can be survived but may include extremity, skull, and lumbar fractures as well as loss of consciousness for a period of time. The ‘Moderate’ injury is broad in definition and in some cases more extreme than the other injury probability models used. The assumption is that a ‘survivable’ crash is one that does not require immediate egress from the rotorcraft or immediate medical care. A seat with an Eiband injury probability of ‘Moderate’

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shows that the impact will cause some sort of injury, though the level and probability of specific types of injury can only be shown in the specific body area criteria.

TABLE II. - SCALE OF INJURY* USED BY CORNELL CRASH INJURY RESEARCH IN CLASSIFYING DEGREE OF BODY INJURY (REF. 51)

	Degree of injury	Classification and description of injury	Degree of injury in this report
		A. Minor or none	
1	No injury		Undebil-itated
2	Minor	"Minor" contusions, lacerations, abrasions in any area(s) of the body. Sprains, fractures, dislocations of fingers, toes, or nose. Dazed or slightly stunned. Mild concussion evidenced by mild headache, with no loss of consciousness.	Moderate
		B. Nondangerous	
3	Moderate	"Moderate" contusions, lacerations, abrasions in any area(s) of the body. Sprains of the shoulders or principal articulations of the extremities. Uncomplicated, simple or green-stick fractures of extremities, jaw, or malar structures. Concussion as evidenced by loss of consciousness not exceeding 5 minutes, without evidence of other intracranial injury.	Moderate
4	Severe but not dangerous (survival normally assured)	Extensive lacerations without dangerous hemorrhage. Compound or comminuted fractures, or simple fractures with displacement. Dislocations of the arms, legs, shoulders or pelvisacral processes. Fracture of transverse and/or spinous processes of the spine, without evidence of spinal-cord damage. Simple fractures of vertebral bodies of the dorsal and/or lumbar spines, without evidence of spinal-cord damage. Compression fractures of L-3-4-5. Skull fracture without evidence of concussion or other intracranial injury. Concussion as evidenced by loss of consciousness from 5 to 30 minutes, without evidence of other intracranial injury.	Moderate
		C. Dangerous to life	
5	Serious-dangerous (but survival probable)	Lacerations with dangerous hemorrhage. Simple fractures of vertebral bodies of the cervical spine, without evidence of spinal-cord damage. Compression fractures of vetebral bodies of dorsal spine and/or of L-1 and L-2, without evidence of spinal-cord damage. Crushing of extremities, or multiple fractures. Indication of moderate intrathoracic or intra-abdominal injury. Skull fracture with concussion as evidenced by loss of consciousness from 5 to 30 minutes. Concussion as evidenced by loss of consciousness from 30 minutes to 2 hours, without evidence of other intracranial injury.	Severe
6	Critical-dangerous (survival uncertain or doubtful)	(Includes fatal terminations beyond 24 hours.) Evidence of dangerous intrathoracic or intra-abdominal injury. Fractures or dislocations of vertebral bodies of cervical spine with evidence of cord damage. Compression fractures of vertebral bodies of dorsal spine and/or L-1, L-2, with evidence of spinal-cord damage. Skull fracture, with concussion as evidenced by loss of consciousness from 30 minutes to 2 hours. Concussion as evidenced by loss of consciousness beyond 2 hours. Evidence of critical intracranial injury.	Severe
		D. Fatal degrees of injury	
7	Fatal within 24 hours of accident	Fatal lesions in single region of the body, with or without other injuries to the 4th degree.	Not used
8	Fatal within 24 hours of accident	Fatal lesions in single region of the body, with other injuries to the 5th or 6th degree.	Not used
9	Fatal	Two fatal lesions in two regions of the body, with or without other injuries elsewhere.	Not used
10	Fatal	Three or more fatal injuries - up to demolition of body	Not used

*Based on observations during first 48 hours after injury and previously normal life expectancy.

Figure 9. Eiband Injury Levels

All criteria are not applicable for every orientation tested. The Pure Vertical orientation is primarily used for injury probability calculation while Combined Horizontal is used to determine structural integrity of the seat. Belt forces in the Combined Horizontal orientation can be used to determine chest injury probability. Combined Vertical is a mixture of both structural testing and injury probability calculation.

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For this effort Nij, peak lumbar force, peak chest acceleration resultant, Eiband, DRZ, and restraint belt forces are reported for the Pure Vertical orientation. Peak chest acceleration resultant and torso restraint belt forces are reported for the Combined Horizontal orientation. UNMIx and UNMIz, Nij, peak chest acceleration resultant, restraint belt forces, and peak lumbar Z force are reported for the Combined Vertical orientation tests. A summary of the criteria used is in Table 5.

Table 5. Injury Criteria Used

	Recommended by FSC	Criteria Used	CV	PV	CH
Head	HIC				
Neck	Nij	Nij	X	X	X
Chest	Belt Loads	Chest Accel Belt Loads	X X	X X	X X
Lumbar	Peak Loads	Peak Load DRI	X X	X X	
Whole Body		Eiband		X	

5.0 RESULTS

5.1 Tests Performed

Tests performed in each cell are shown in Table 6 and are indicated by test facility ID (either HIA or VDT, and the test number specific to that facility). The H-60A/L aft-facing seat was not tested in the Pure Vertical orientation as the forward-facing and aft-facing seats are fundamentally the same. It is assumed that H-60A/L forward-facing seat testing in the PV orientation is applicable for H-60A/L aft-facing seats. Not all cells were completed for each seat due to structural failures shown at lower levels. Cells where the seat was not tested are shown with an X. Several cells were repeated for some seats. In some cases the same seat was used. In other cases modification to the seat were made due to structural issues, requiring a repeat of the cell.

Table 6. Tests Performed

Cell	H-60A/L Fore	H-60A/L Aft	UH-60M	Wolf	Glatz
A	VDT6219	VDT6233	VDT6227	VDT6221 VDT6231	VDT6222
B	VDT6220	VDT6234	VDT6228	VDT6232	VDT6223
C	VDT6224	VDT6235	VDT6229	X	VDT6226
D	VDT6225	VDT6236	VDT6230	X	X
E	HIA8507	HIA8516	HIA8511	HIA8509	HIA8508 HIA8510
F	X	X	HIA8515	X	X
G	VDT6245 VDT6246	X	VDT6237 VDT6238	VDT6242 VDT6243	VDT6253

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H	VDT6247	X	VDT6239	VDT6244 VDT6248	VDT6254
I	VDT6251	X	VDT6240	VDT6249	VDT6255
J	VDT6252	X	VDT6241	VDT6250	VDT6256

Consistency of test conditions measured on the carriage is shown in Table 7. Typically a successful test is within +/- 2% of a nominal peak acceleration level. As all seats tested are designed for one-time use, testing levels were kept consistent regardless if a nominal peak acceleration level was achieved or not. Sample variances of test parameters are shown in parentheses.

Table 7. Test Condition Statistics

Cell	Mean Peak Acceleration (G)	Mean Velocity (ft/s)	Mean Rise Time (ms)
A	23.36 (0.17)	38.65 (0.01)	30.47 (0.33)
B	34.94 (0.43)	48.31 (0.01)	25.82 (0.32)
C	25.35 (0.32)	40.48 (0.00)	29.25 (0.15)
D	36.35 (0.16)	48.89 (0.01)***	25.07 (0.12)
E	17.71 (0.11)	45.71 (0.12)	77.83 (24.57)
F	24.15*	52.85*	62.00*
G**	16.44 (0.40)	31.61 (0.23)	34.70 (0.37)
H	33.83 (0.09)	46.24 (0.00)	26.38 (0.07)
I	16.17 (0.06)	30.89 (0.00)	35.13 (0.26)
J	34.89 (0.01)	46.93 (0.00)	26.43 (0.04)

*One test run in cell
**Low end of stroke
***Velocity of one test not recorded

5.2 Test-by-Test Description

A summary of structural issues with the seats is located in Appendix B. A structural failure in this study was one where the seat did not adequately hold the occupant in the seat after the pulse. Cable breaks, fabric rips, and seat mount point detaching from mounting points are reported, though many of these are not considered as complete structural failures of the seat. It is realized that this is counter to qualification testing of seats.

Pictures from individual tests are located in Appendix C.

VDT6219 – Cell A, CV, H-60A/L forward-facing, LOIS, 23.76G, 38.58ft/s, 31ms rise time
VDT6219 was the first CV test with the H-60A/L forward-facing seat. The top mount hooks were not wrapped with tape like the remaining tests. The front cable (from front bottom mounts to the front of the seat pan) lengths were 19”. Load cells were placed on both torso and both lap restraint belts. The seat legs did not stroke during impact. All feet remained attached to the floor

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attachments except the front right. The top attenuators stroked ~1.25", and both top hooks remained in the top mounts. The helmet rotated forward on the manikin head. Left lap restraint force data was bad. Peak lumbar Z force was 962 lb at 55ms after T=0. Upper Nij tension-extension was 0.5537, or equivalent to a 20% probability of an AIS >=2 injury. It is unknown whether or not this was due to the helmet rotation during the impact. After impact the restraint buckle released with 38 lb of force.

VDT6220 – Cell B, CV, H-60A/L Forward, LOIS, 35.7G, 48.29ft/s, 25.2ms rise time
VDT6220 was the first CV impact test at a higher energy level. The front cable lengths were 18.75". The top mounts were not taped. The seat legs did not stroke during impact. The seat fabric did not rip. All attachment points remained secure. There was a peak lumbar Z force of 1103 lb. The helmet did not rotate significantly on the manikin head. There was an upper Nij tension-extension of 1.5822, or equivalent to a 46% probability of an AIS >=2 injury. Seat fixture Y accelerometer was bad as well as both lap belt forces. The restraint buckle released with 12 lb force post-test.

VDT6221 – Cell A, CV, Wolf, LOIS, 23.2G, 38.67ft/s, 31.2ms rise time
VDT6221 was the first test with the Wolf prototype seat. The seat broke in multiple places upon impact. The top right mount consisted of a bolt through an aluminum tube. The bolt sheared through the aluminum tube on the right side, and partial shearing of the left side was seen post-test. A resultant 2786 lb force was recorded in the top left seat mount. A resultant of 2263 lb was recorded in the top right mount prior to the seat structure breaking. The seat did not stroke. Also, the feet of the seat were intended to rest on the floor of the aircraft. Plastic blocks were placed adjacent to the seat mounts to simulate the floor. However, the feet broke during the impact, most likely due to the seat structure collapsing during the impact from failure of the upper mounts. The seat back was torn during impact close to where the lower neck load cell resides in the manikin. For subsequent tests, layers of duct tape were placed over the edges of the lower neck load cell to prevent tearing. A peak lumbar Z force of 1506 lb was recorded during the impact. The restraint buckle disengaged with 12 lb of force.

VDT6222 – Cell A, CV, Glatz, LOIS, 23.2G, 38.66ft/s, 29.6ms rise time
VDT6222 was the first test with the Glatz prototype seat. Lap belt load cells were not used during the test. Pre-tensioning of the lap belts was made with a fish-hook scale. The manikin pelvis was located ~1-2" in front of the seat back as the belts were tightened as far as possible. The seat experienced ripping in a few locations, though it structurally held the manikin during the impact. The seat anchor points on the floor were deformed during the impact. The 1-inch webbing on the back and side of the seat tore freely out of the seat structure. The manikin was forced out and down-right in the seat pan. A peak lumbar Z force of 1019 lb was recorded during the impact. The seat pan accelerometer package was placed underneath the seat cushion, thus direct comparison of the seat pan accelerations to other seats in this orientation is not possible.

VDT6223 – Cell B, CV, Glatz, LOIS, 35.26G, 48.37ft/s, 25.4ms rise time
VDT6223 was a structural failure of the seat. The front right webbing that held the seat cushion ripped and allowed the seat cushion and manikin to submarine. The right lap restraint belt ripped free from the seat structure. The manikin was ultimately hung by the torso restraints still

attached to the buckle. The cause of the seat structure ripping was due to a manufacturing error according to Glatz Aeronautical. Fixes to the seat were applied to tests VDT6256 and HIA8510 by lengthening the structural webbing further around the front of the seat pan. Also, the lap restraint belts were lengthened behind the seat pan in later tests to prevent the complete separation of the lap belt from the seat. Seat attachment points were again deformed but did not break. A peak lumbar Z force of 1153 lb was recorded, though comparison to other testing is not valid due to structural failure of the seat.

VDT6224 – Cell C, CV, H-60A/L forward-facing, LARD, 25.47G, 40.51ft/s, 29.8ms rise time

VDT6224 was the first test using the LARD manikin. The seat structurally survived and stroked 6.75" on the left and 7.125" on the right. However, after the initial impact, the seat and manikin rebounded and the left attachment hook came off the top mount. To prevent this from happening in subsequent tests, the top attachment points were wrapped with tape and secured with zip ties to ensure the seat remained attached to the fixture. This is a non-standard installation method. The seat pan fabric ripped on the front tube. All floor attachments remained fixed. A peak lumbar Z force of 929 lb was recorded. The feet of the manikin remained on the floor during the impact, possibly off-loading some of the force into the seat. All data during the test were recorded successfully. The restraint buckle disengaged with 22 lb force.

VDT6225 – Cell D, CV, H-60A/L forward-facing, LARD, 36.67G, 48.96ft/s, 24.7ms rise time

VDT6225 was the first test at the high energy level with LARD. The feet of the manikin remained on the floor during the impact. The seat pan fabric ripped from side to side during the impact. The seat stroked 10" on the left and 10.25" on the right. All mounting points remained secured to the fixture. The seat pan strut extended during the impact 2.125". A peak lumbar Z force of 778 lb was recorded during the test. This force is relatively low most likely due to the seat pan ripping. The seat pan X and Z accelerometers were broken during the test. All the remaining data channels were successfully collected. The restraint buckle disengaged with 36 lb force.

VDT6226 – Cell C, CV, Glatz, LARD, 25.82G, 40.48ft/s, 28.9ms rise time

VDT6226 was the first test with LARD in the Glatz seat. The seat structurally failed in multiple places, causing the manikin to be completely unrestrained in the seat. During impact the manikin submarined and was momentarily hung by the torso belts still attached to the rotary buckle. The right rear side webbing pulled out of the seat structure. The front right seat pan structure ripped. This was again due to manufacturer error, according to Glatz Aeronautical. The original aluminum mounting feet used during the first two Glatz tests with LOIS were replaced with stainless steel feet. The new feet did not show any signs of deformation. Both lap belts ripped from the seat. There was an Nij tension-flexion value of 0.6815, or equivalent to a 22% probability of an AIS >=2 neck injury. Since the seat structurally failed, lumbar load and seat pan acceleration are meaningless and are not comparable to other seat tests. The left torso restraint belt force channel went bad well after the impact. All other data were successfully recorded. The restraint buckle disengaged with 9 lb force.

VDT6227 – Cell C, CV, UH-60M, LARD, 25.56G, 40.53ft/s, 29.1ms rise time

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VDT6227 was the first LARD test with the UH-60M seat. The right foot of the seat disengaged during the impact. After further inspection it was found there was some interference with the AFRL mounting points and that the foot may have not been fully engaged. A modification to the mounting bracket was made after VDT6228, and in subsequent tests, the feet stayed attached. Even with the foot becoming disengaged, the seat stroked 4.625”. The only structural damage observed was slight deformation in the seat pan. A peak lumbar Z force of 1346 lb was recorded. All data were successfully collected. The restraint buckle disengaged with 8 lb force.

VDT6228 – Cell D, CV, UH-60M, LARD, 36.49G, 39.85ft/s, 25.1ms rise time
The UH-60M seat stroked 8.375” during this test. The vertical webbing on the side panel tore on the right side of the seat pan. The lap belt force sensors were not used due to lack of available webbing and space. The right foot of the seat again came loose. After further inspection it was found there was some interference with the AFRL mounting points and that the foot may have not been fully engaged. A modification to the mounting foot was made, and in subsequent tests, the feet stayed attached. There was slight deformation in the seat pan. A peak lumbar Z load of 1284 lb was recorded during the impact. The seat pan accelerometers along with the chest Z accelerometer did not produce data. The restraint buckle disengaged with 5 lb of force.

VDT6229 – Cell A, CV, UH-60M, LOIS, 23.96G, 38.7ft/s, 30.5ms rise time
VDT6229 was the first test with LOIS on a UH-60M seat. The seat stroked 1.25”. After modification to the seat mounting points on the test fixture during VDT 6227 and VDT6228, the seat feet stayed engaged during the entirety of the test. Post-test a slight deformation of the seat pan was shown. A peak lumbar Z force of 1156 lb was recorded. All data channels were collected successfully.

VDT6230 – Cell B, CV, UH-60M, LOIS, 34.39G, 48.40ft/s, 26.5ms rise time
The manikin’s feet appeared to stay on the floor of the fixture. The seat stroked 3.0”. Peak lumbar Z force was 1484 lb. The restraint buckle released with 4.5 lb of force. Post-test it was observed that there was slight deformation of the seat pan during the impact. All data channels were successfully collected.

VDT6231 – Cell A, CV, Wolf, LOIS, 22.94G, 38.75ft/s, 30.3ms rise time
VDT6231 was a repeat of VDT6221 that incorporated structural changes to the seat. The first change was the inclusion of steel inserts into the top seat mount where the structure failed during test VDT6221. An additional hole in the aluminum tubing was drilled at a different axis to mount the steel fitting. The second change was the use of steel feet to ensure the seat did not dislodge from the fixture. It was understood that this change would not be appropriate for a production seat. However, this change was necessary to see how the seat performed. Both changes were successful in that the seat did not experience structural failure like VDT6221. The seat locking mechanism that prevents the seat from stroking engaged successfully, though the seat did not stroke during the impact. The friction brake appeared to provide too much force, preventing the seat structure to stroke. A peak lumbar Z force of 1396 lb was recorded. The restraint buckle disengaged with 10 lb of force. All data channels were successfully collected.

VDT6232 – Cell B, CV, Wolf, LOIS, 35.24G, 48.33ft/s, 25.7ms rise time

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VDT6232 was the last test with the Wolf seat in the CV orientation. As with VDT6231, changes were incorporated to both the top and lower mounts of the seat to the fixture. The seat locking mechanism that prevents stroking appears to have disengaged. Similar to VDT6231, the seat did not stroke during impact. A peak lumbar Z force of 2032 lb was recorded. The top hanger bent during the impact, though this was the only structural damage seen on the seat. All data were collected successfully. The restraint buckle disengaged with 13.5 lb of force.

VDT6233 – Cell A, CV, H-60A/L aft-facing, LOIS, 23.23G, 38.56ft/s, 30.2ms rise time
VDT6233 was the first test of the H-60A/L aft-facing seat. The top mounting hooks were wrapped with tape and secured with zip-ties, preventing inadvertent release during rebound after the primary impact. All mounting points successfully stayed attached during impact. The seat stroked 3.5”. The manikin did sink into the backpack pouch. No other structural damage was noted on the seat. A peak lumbar Z force of 602 lb was recorded. All data were successfully collected. The restraint buckle disengaged with 29 lb of force.

VDT6234 – Cell B, CV, H-60A/L aft-facing, LOIS, 34.13G, 48.17ft/s, 26.3ms rise time
The top mounting hooks were taped and zip-tied to ensure they did not disengage during rebound of the seat after the impact. The back floor feet were also secured to ensure they did not disengage. The seat stroked 5.125” during the impact. The manikin was pushed into the backpack pouch, and the seat pan fabric ripped on the left side. A peak lumbar Z force of 810 lb was recorded. All data were successfully collected. The restraint buckle disengaged with 21 lb of force.

VDT6235 – Cell C, CV, H-60A/L aft-facing, LARD, 24.53G, 40.41ft/s, 29.2ms rise time
VDT6235 was the first H-60A/L seat test in the CV orientation with LARD. The seat stroked 8.5” on the left and 7.75” on the right. The seat and manikin rebounded after the test, though the manikin was held in the seat. The front right foot of the seat came off the mount. The seat pan fabric started to tear on both sides of the seat. A peak lumbar Z force of 564 lb was recorded. The restraint buckle disengaged with 13 lb of force.

VDT6236 – Cell D, CV, H-60A/L aft-facing, LARD, 35.90G, 48.82ft/s, 25.4ms rise time
VDT6236 was the last CV test of the program. The seat tested was a new seat that had been in storage and was never used operationally. The seat stroked 12.5” on the left and 11.5” on the right. Tearing of the seat pan on both sides occurred. The front left seat mount came off during the impact. The manikin sank into the backpack pouch. A peak lumbar Z force of 632 lb was recorded. Seat pan accelerometer Y channel went bad during the test, though the remaining data were collected successfully. The restraint buckle disengaged with 13 lb of force.

VDT 6237 – Cell G, PV, UH-60M, LOIS, 13.91G, 28.83fts, 36ms rise time
VDT6237 was the first test in the Pure Vertical orientation. The seat did not stroke at 13.91G on the carriage (resulting in 20.12G on the seat pan). The UH-60M seat was not designed to stroke at this low acceleration level, especially with a small female occupant. The seat was subsequently reused for VDT6238. A peak chest resultant of 28.79G and a peak lumbar Z of 1207 lb were recorded. No Nij criteria were exceeded. The buckle released with 6 lb of force.

VDT 6238 – Cell G, PV, UH-60M, LOIS, 15.52G, 30.89ft/s, 35.4ms rise time

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VDT6238 was a repeat of VDT6237 but at a higher peak G to stroke the seat. The seat was reused from VDT6237. The seat stroked less than ½", at a peak G of 15.52G and 30.89 ft/s measured at the structure, resulting in a peak G of 26.84G measured at the seat pan. No structural damage to the seat was recorded. A peak chest resultant of 28.79G was recorded along with a peak lumbar Z force of 1385 lb. An upper neck tension-flexion of 0.5505 was calculated, resulting in a 20% probability of an AIS >=2 neck injury during impact. The restraint buckle released with 5.5 lb of force.

VDT 6239 – Cell H, PV, UH-60M, LOIS, 33.41G, 46.19ft/s, 26ms rise time
VDT6239 was the first LOIS PV shot at the higher energy level. The seat stroked 5.375" during impact, resulting in a peak lumbar force of 1186 lb. This is in the same range as VDT6238 at 15.52G, showing the seat stroked properly. A peak chest resultant of 31.62G was recorded. A neck compression-flexion of 0.5231 was calculated, resulting in a 19% probability of an AIS >=2 neck injury. The restraint buckle released with 6 lb of force.

VDT6240 – Cell I, PV, UH-60M, LARD, 16.14G, 30.83ft/s, 35.7ms rise time
VDT6240 was the first PV with LARD. The seat stroked 1.675" during impact. There was some slight deformation in the seat pan recorded post-test, though the seat was structurally sound during the impact. A peak chest resultant of 25.99G was recorded. A peak lumbar Z force of 1504.18 lb was recorded as well as a peak seat cushion Z acceleration of 27.16G. No neck injury criteria were exceeded during the impact. The restraint buckle released with 6 lb of force.

VDT6241 – Cell J, PV, UH-60M, LARD, 34.91G, 46.98ft/s, 26.2ms rise time
The seat stroked 11.5" during the impact. There was deformation in the seat pan as well as bending in the seat pan rotation point, though the seat structurally held together and restrained the manikin during the impact. A very high but short seat cushion Z acceleration of over 100G was recorded – considerably higher than any other test. This was probably due to the seat reaching the full stroking distance. A peak chest resultant of 46.6G was recorded as well as a peak lumbar Z force of 1421 lb; the peak lumbar Z force is lower than VDT6240 with a peak carriage acceleration half that of VDT6241. No neck injury criteria were exceeded during the impact. The restraint buckle released with 6 lb of force.

VDT6242 – Cell G, PV, Wolf, LOIS, 14.79G, 30.89ft/s, 35.1ms rise time
VDT6242 was the first PV test with the Wolf seat. The Wolf seat was designed to nominally unlock and stroke at ~15G with a 50%ile male. The seat locking mechanism that keeps the seat from stroking did not unlock during this test, and the seat was reused for VDT6243. A peak lumbar Z force of 986 lb was recorded. A 23.74G peak Z acceleration was recorded on the seat pan. A peak chest resultant of 24.67G was recorded. No neck injury criteria were exceeded during the impact. The restraint buckle released with 9 lb of force.

VDT6243 – Cell G, PV, Wolf, LOIS, 16.78G, 31.82ft/s, 34.3ms rise time
VDT6243 was a repeat of VDT6242 at a slightly higher acceleration level, attempting to make the Wolf seat stroke. As with VDT6242, the seat locking mechanism did not disengage, preventing the seat from stroking. A peak lumbar Z force of 1009 lb was recorded as well as a peak chest resultant of 25.08G. The restraint buckle released with 13 lb of force.

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VDT6244 – Cell H, PV, Wolf, LOIS, 34.24G, 46.29ft/s, 26.6ms rise time
VDT6244 is the last PV test with LOIS on the Wolf seat. The seat locking mechanism engaged; however the seat did not stroke during the impact. This was likely due to the braking pads providing too much friction to allow the seat the stroke. Ripping of the seat pan fabric was observed during the impact as well as ripping of the upper seat back. The upper seat back damage most likely was due to the lower neck load cell which sticks out of the manikin. A chest resultant of 41.64G was recorded as well as a peak lumbar Z force of 1569 lb. An Nij neck tension-extension of 1.2084 was calculated, resulting in a 35% probability of an AIS >=2 neck injury. There was rotation of the helmet during the impact.

VDT6245 – Cell G, PV, H-60A/L forward-facing, LOIS, 14.87G, 30.83ft/s, 35.3ms rise time
VDT6245 was the first PV test with the H-60A/L seat. The seat did not stroke during impact. No damage to the seat was observed after inspection and the seat was reused for VDT6246. A peak chest resultant of 19.31G was recorded. A peak lumbar Z force of 760 lb and a peak seat cushion Z acceleration of 17.71G were recorded. The restraint buckle released at 15 lb.

VDT6246 – Cell G, PV, H-60A/L forward-facing, LOIS, 16.55G, 31.89ft/s, 34.1ms rise time
VDT6246 was a repeat of VDT6245 at a slightly higher acceleration pulse. The seat was reused from VDT6245 as no damage was observed. The seat did not stroke during VDT6246, though the front seat pan fabric ripped along the pan frame. A peak chest acceleration resultant of 23.23G was recorded as well as a peak lumbar Z force of 902 lb. A seat pan Z acceleration of 46.42G was recorded. The restraint buckle released at 15 lb.

VDT6247 – Cell H, PV, H-60A/L forward-facing, LOIS, 33.91G, 46.25ft/s, 26.5ms rise time
VDT6247 was the last PV with LOIS using the H-60A/L seat. The seat stroked 3.25" during impact. The rear of the seat pan ripped, though the manikin was successfully held in the seat. Lap belt tension was not recorded during the test due to available belt length. A very short Z acceleration of 54.75G was recorded. A peak lumbar Z force of 1104 lb during the impact as well as a 31.03G peak chest resultant acceleration were observed. An Nij tension-extension of 0.5763 was calculated, resulting in a 20% probability of an AIS >=2 neck injury. The restraint buckle released with 9 lb of force.

VDT6248 – Cell H, PV, Wolf, LOIS, 33.74G, 46.18ft/s, 26.6ms rise time
VDT6248 was a repeat of VDT6244 which included modification to the braking mechanism. The brake pads were replaced with a different compound. The seat stroked 3.75" during the impact. The side of the seat fabric ripped as well as the top fabric of the seat back. The seat back ripping was most likely due to the lower neck load cell which protrudes out of the manikin. A chest resultant acceleration of 35.72G was recorded along with a peak lumbar Z force of 1068 lb. A peak seat pan acceleration Z of 54.75G was recorded. A Nij tension-extension of 1.2130 was calculated, resulting in a 35% probability of an AIS >=2 neck injury. The restraint buckle released with 9 lb of force.

VDT6249 – Cell I2, PV, Wolf, LARD, 21.51G, 36.3ft/s, 31.3ms rise time
To ensure the Wolf seat would stroke, a higher nominal peak acceleration was executed for VDT6249. The same modification to the seat as VDT6248 with replacing the brake pads was made. The seat locking mechanism successfully disengaged and the seat stroked 2.25". There

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was a tear in the upper seat back, even though the lower neck load cell used for LARD does not protrude from the manikin. A peak chest acceleration resultant of 35.72G was recorded during the impact as well as a peak lumbar Z force of 1068 lb. A peak seat pan Z acceleration of 44.00G was recorded. No neck injury criteria were exceeded during the impact. The restraint buckle released with 5 lb of force.

VDT6250 – Cell J, PV, Wolf, LARD, 34.72G, 46.98ft/s, 26.7ms rise time
VDT6250 was the last PV test with LARD and the Wolf seat. The seat included the modification to the brake pads like VDT6248 used during VDT6248 and VDT6249. The seat locking mechanism successfully disengaged and the seat stroked 12.125". There again was tearing of the upper seat back as well as a small tear at the lower left side of the seat back. A peak chest resultant acceleration of 25.28G was recorded as well as a 1462 lb peak lumbar Z force. A peak seat pan Z acceleration of 25.94G was recorded. No neck injury criteria were exceeded. The restraint buckle released with 6 lb of force.

VDT6251 – Cell I, PV, H-60A/L Forward-facing, LARD, 16.42G, 30.94ft/s, 35ms rise time
VDT6251 was the first PV test for the H-60A/L seat with LARD. The seat successfully stroked 2.5" during impact. No structural issues with the seat were found post-test as the seat successfully held the manikin during the impact. A peak chest resultant of 18.61G was recorded as well as a peak lumbar Z force of 1162 lb. A peak seat pan Z acceleration of 20.14G was recorded. No neck injury criteria were exceeded. The restraint buckle released with a 15 lb force.

VDT6252 – Cell J, PV, H-60A/L Forward-facing, LARD, 34.92G, 46.9ft/s, 26.4ms rise time
VDT6252 was the last PV test with the H-60A/L seat. The seat stroked 11.75in. There was significant tearing of the right side of the seat pan along the seat pan structure. The front left mounting point failed and tore away. The bottom left front mounting Y force channel was bad during the test. The lumbar moment about the Y axis peaked at the set range of the channel. A peak chest acceleration resultant of 45.19G was recorded along with a peak lumbar Z force of 1752 lb. A seat pan acceleration of 37.41G was recorded during the pulse, and a higher 72.81G was recorded soon after. This was most likely due to the ripping and subsequent bottoming out of the seat on the fixture, and was consistent with the peak lumbar forces recorded. No neck injury criteria were exceeded. The restraint buckle released with 15 lb of force.

VDT6253 – Cell G, PV, Glatz, LOIS, 16.92G, 31.85ft/s, 35ms rise time
VDT6253 was the first PV test with the Glatz seat. Lap belt tension was not recorded due to the length of the belts. Seat pan acceleration Y went bad after the primary pulse. There was no structural damage to the seat during the test. The seat pan accelerometer package was placed on top of the cushion for the PV testing, unlike during the CV testing. Because of this configuration, seat pan data can be directly compared to other PV seat tests. There was a peak seat pan Z acceleration of 45.88G. A peak chest acceleration resultant of 26.22G was recorded along with a peak lumbar Z force of 939 lb. No neck injury criteria were exceeded. The restraint buckle released with 5 lb of force.

VDT6254 – Cell H, PV, Glatz, LOIS, 33.85G, 46.29ft/s, 26.2ms rise time

The lap belt forces were not collected during the test due to space and the length of available belt. All other data channels were successfully collected. The manikin could not be fully pushed back into the seat due to the length of the seat pan. The helmet rotated on the manikin's head during the impact and the seat cushion started to fall out of the seat pan. A peak chest acceleration resultant of 26.22G was recorded along with a peak lumbar Z force of 1360 lb. A peak seat pan Z acceleration of 75.22G was recorded. Nij tension-extension, compression-flexion, and compression-extension limits were exceeded with values of 1.0350 and 0.5235, and 0.5865, respectively. These values correlate with a net 31% probability of an AIS >=2 neck injury.

VDT6255 – Cell I, PV, Glatz, LARD, 15.94G, 30.89ft/s, 34.7ms rise time
VDT6255 was the first PV test for the Glatz seat with the LARD manikin. All data channels were successfully collected. The seat cushion started to come out of the seat pan and the front right corner of the seat pan started to rip. The right lap belt started to rip out of the seat bucket. A peak chest acceleration resultant of 26.19G was recorded as well as a peak lumbar Z force of 897 lb. A peak seat cushion Z acceleration of 14.77 was recorded. No neck injury criteria were exceeded. The restraint buckle released with 4 lbs of force.

VDT6256 – Cell J, PV, Glatz, LARD, 34.99G, 46.85ft/s, 26.4ms rise time
VDT6256 used a modified Glatz seat. Additional webbing was placed on the back of the seat, the structural webbing down the side panel of the seat was extended around the front of the seat pan, and the lap belt webbing was extended behind the seat pan. The lap belt forces were not collected due to space and length of available belts. All other data channels were successfully collected. During impact the webbing to the front feet came loose as the seat pan descended and put tension on the webbing. The seat cushion started to come of the seat bucket, and the structural webbing on the right side panel ripped out. The back of the seat pan ripped, and the lap belts ripped out of the seat back. One of the tension rods at the top of the seat broke. A peak chest acceleration resultant of 44.34G was recorded along with a peak lumbar Z force of 1251 lb. The seat pan acceleration Z was noisy – most likely due to stitching in the seat coming out. A peak seat cushion Z acceleration of 21.86G was recorded. No neck injury criteria were exceeded. The restraint buckle released with 4.5 lbs.

HIA8507 – Cell E, CH, H-60A/L Forward-facing, LARD, 17.74G, 45.66ft/s, 81ms rise time
HIA8507 is the first CH test of the program. All data channels were successfully collected. The seat energy attenuators stroked 9.25" on the left and 10.5" on the right during the impact. The left seat pan strut extended 0.75". The cable that runs from the right back foot to the left back seat pan broke. The manikin began to submarine out of the seat. The right torso belt had a peak force of 910 lb while the left lap had a peak force of 744 lb. A peak chest resultant of 28.49G was recorded. No neck injury criteria were exceeded. The restraint buckle released at 48 lb force.

HIA8508 – Cell E, CH, Glatz, LARD, 18.05G 46.15ft/s, 71ms rise time
HIA8508 was the first CH test with the Glatz seat. The lumbar My channel maxed out. The seat was the standard seat without the modifications added for VDT6256. As the seat moved towards the piston during the impact, the back webbing straps broke loose from the seat. When this occurred the seat pan essentially had no connection with the steel floor mounting points and the

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seat was free to swing from the top hooks. The right lap belt broke loose from the seat structure, and the front right seat bucket tore loose, allowing the seat cushion to fly unrestrained. The manikin submarined in the seat, though the additional tethers on the manikin torso caused the manikin to 'pendulum' up. The left torso restraint disconnected from the restraint buckle. The left torso belt had 1204 lb prior to disconnection. Nij tension-extension exceeded the limit of 0.5 with a value of 0.8389 resulting in a 26% probability of an AIS>=2 neck injury.

HIA8509 – Cell E, CH, Wolf, LARD, 17.58G, 45.97ft/s, 81ms rise time
HIA8509 was the only CH test with the Wolf seat. All data channels were successfully collected. The seat structure broke in several places. The right mount broke completely while the left showed signs of stretching. The left foot pulled and stripped away the mounting button. The seat structure broke along welds holding the top of the seat. The right torso belt had a peak force of 998 lb. The left lap belt had a peak of 1795 lb while the right had a peak of 1228 lb. The peak chest resultant acceleration was 28.25G. No neck injury criteria were exceeded. The restraint buckle released with 10 lb force.

HIA8510 – Cell E, CH, Glatz, LARD, 18.15G, 45.83ft/s, 72ms rise time
HIA8510 was a repeat of HIA8508 using a modified seat. The modifications were the same as the seat used in VDT6256: additional webbing was placed on the back of the seat, the structural webbing down the side panel of the seat was extended around the front of the seat pan, and the lap belt webbing was extended behind the seat pan. The lap belt load cells were not used during the testing. The left torso load cell did not collect good data during impact. The seat structurally failed similarly to HIA8508. When the 1" webbing broke connecting the seat pan to the floor, the seat pan was allowed to move freely and rotate on the top mounts. Tethers on the manikin's torso and legs prevented the manikin from coming off the sled. The manikin submarined in the seat. The lab belts ripped away from the side panels, though they stayed attached to the seat as the webbing continued behind the seat pan. The front right of the seat pan did not rip as in HIA8508. Peak chest acceleration resultant was 24.17G. Nij tension-flexion and compression-flexion failed at 0.6515 and 0.8480, respectively, resulting in a 26% probability of an AIS >=2 neck injury.

HIA8511 – Cell E, CH, UH-60M, LARD, 17.28G, 45.17ft/s, 80ms rise time
HIA8511 was the first CH test with the UH-60M seat. All data channels were collected successfully. The seat structurally held together and all mounts held. The seat pan had minor deformation. The right torso belt had a peak force of 1447 lb. The left lap had a peak force 2187 lb while the right had a peak force of 1544 lb. The peak chest acceleration resultant was 26.89G. No neck injury criteria were exceeded. The restraint buckle released with 5 lb of force.

HIA8515 – Cell F, CH, UH-60M, LARD, 24.15G, 52.85ft/s, 62ms rise time
HIA8515 was the only test of Cell F that was conducted. All data channels were collected successfully. The bottom left mount broke first at 3769 lb. The bottom right broke next at 3342 lb, causing the seat to swing on the top mounts. The peak chest acceleration resultant was 35.37G. No neck injury criteria were exceeded during the pulse. The restraint buckle released with a 5 lb force.

HIA8516 – Cell E, CH, H-60A/L Aft-facing, LARD, 17.47G, 45.48ft/s, 82ms rise time

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HIA8516 was the only aft-facing CH test performed. The seat tested was a new seat that had been in storage and was never used operationally. The energy attenuators extended 7.0”. The right wire bender and the support cable that goes from the left foot to the right seat pan broke during impact. Both seat pan struts extended 2.75”. The arms of the manikin came in contact with the vertical structure of the fixture, potentially lowering the forces into the seat. The peak chest acceleration resultant was 35.56G. No neck injury criteria were exceeded. The restraint buckle released with a 16 lb force.

6.0 DISCUSSION

6.1 Combined Vertical Tests

Peak torso belt forces, Chest Resultant G, peak lumbar Z force, DRZ, Nij, UNMIx, and UNMIz are reported for the CV orientation tests.

Table 8 shows the injury comparison results for Cell A, nominally a 23.36G shot with a velocity of 38.65 ft/s. Cells shown in red have exceeded the injury criteria. It should be noted that the Wolf seat did not stroke in either VDT5221 or VDT6231, thus these tests can only be compared as a non-stroking seat with a seat pan that flips down and no front mounting points. The restraint belt forces for the H-60A/L Aft seat were negligible as the manikin was forced into the seat. All peak torso belt forces were below the established injury threshold of 2000 lb. The Glatz seat had the highest chest acceleration resultant at 40.66G. The H-60A/L aft-facing seat had the lowest peak lumbar Z force of 602 lb. This is most likely due to the manikin slipping into the backpack pouch during the impact. All seats, except the H-60A/L aft- and forward-facing seats, would have failed the Desjardins lumbar force criteria of 963 lb for the small occupant.

Table 8. CV Cell A LOIS Injury Comparison Results

Test #	**Seat**	**Torso Belts Peak Force**	**Chest Resultant G**	**Peak Lumbar Z Force (lb)**	**DRZ**
VDT6233	H-60A/L AFT	57	21.59	602	22.93
VDT6219	H-60A/L FORE	703	26.33	962	28.63
VDT6222	Glatz**	700	40.66	1019	30.78**
VDT6229	UH-60M	804	31.74	1156	31.55
VDT6221	Wolf*	651	31.75	1518	33.44
VDT6231	Wolf*	824	35.12	1396	36.89

*seat did not stroke

**seat pan accelerometers under seat cushion

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Table 9 summarizes the Nij neck injury data for Cell A. Cells shown in red have exceeded the injury criteria. All forward facing seats had a greater than 10% probability of an AIS >=2 neck injury; however the H-60A/L aft-facing seat passed all of the neck injury criteria.

Table 9. CV Cell A LOIS Neck Injury Comparison

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6233	H-60A/L AFT	0.2069	0.1713	0.2836	0.2011	0.2836	0.09489	0.05808
VDT6219	H-60A/L FORE	0.2612	0.5537	0.2941	0.1246	0.5537	0.18812	0.10390
VDT6222	Glatz**	0.0500	0.6916	0.1308	0.4810	0.6916	0.20466	0.06068
VDT6229	UH-60M	0.4581	0.5958	0.3498	0.4551	0.5958	0.17341	0.03917
VDT6221	Wolf*	0.0000	0.4299	0.6058	0.1228	0.6058	0.16310	0.11859
VDT6231	Wolf*	0.3796	1.2354	0.4068	0.4490	1.2354	0.26121	0.07328

*seat did not stroke
**seat pan accelerometers under seat cushion

Table 10 summarizes the injury comparison results for Cell B with a LOIS manikin. Cell B has a nominal pulse of 34.94G at 48.31 ft/s. Cells shown in red have exceeded the injury criteria. As with Cell A, the aft-facing H-60A/L seat had the lowest restraint force values. All seats passed the peak torso belt force limit of 2000 lb. The Glatz seat tore apart and did not successfully restrain the manikin. The H-60A/L seat had a significantly lower chest resultant acceleration and peak lumbar Z force than the UH-60M seat. All seats, except the H-60A/L aft-facing seat, failed the lumbar force criteria of 963 lb force for the small occupant.

Table 10. CV Cell B LOIS Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6234	H-60A/L AFT	79	33.71	810	28.43
VDT6220	H-60A/L FORE	1351	29.34	1103	32.06
VDT6223	Glatz**	1138	46.89	1153	39.47**
VDT6230	UH-60M	1073	48.26	1484	43.03
VDT6232	Wolf*	906	53.34	2032	51.39

*seat did not stroke
**seat structural failure, seat pan accelerometers under seat cushion

Table 11 summarizes the neck injury data for Cell B with LOIS. Cells shown in red have exceeded the injury criteria. All forward-facing seats exceeded the tension-extension limits of Nij for the LOIS occupant. The Wolf seat also exceeded the compression-flexion criteria, due to the seat not stroking as intended.

Table 11. CV Cell B LOIS Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6234	H-60A/L AFT	0.0940	0.1209	0.2825	0.0682	0.2825	0.20946	0.08761
VDT6220	H-60A/L FORE	0.0436	1.5822	0.2815	0.1653	1.5822	0.20567	0.07467
VDT6223	Glatz**	0.7968	1.6599	0.1754	0.2770	1.6599	0.42982	0.13814
VDT6230	UH-60M	0.0615	1.8299	0.4782	0.4707	1.8299	0.28529	0.07803
VDT6232	Wolf*	0.0476	1.0310	0.7530	0.2848	1.0310	0.30144	0.04110

*seat did not stroke
**seat structural failure, seat pan accelerometers under seat cushion

Table 12 summarizes the injury results for Cell C (25.35G, 40.48 ft/s). Cells shown in red have exceeded the injury criteria. The Wolf seat was not tested for this Cell given the issues encountered during Cell A and B. The Glatz seat structurally failed and allowed the manikin to submarine and become unrestrained during the impact. The torso belt forces were high as the manikin hung by its neck. As with Cells A and B, the H-60A/L aft-facing seat had the lowest belt force as the manikin was forced into the seat back pouch. The peak lumbar Z force for the UH-60M seat was the highest at 1346 lb while the H-60A/L aft seat was the lowest at 564 lb. However, the UH-60M seat is within the proposed 2235 lb lumbar force limit for the large occupant.

Table 12. CV Cell C LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6235	H-60A/L AFT	71	28.9	564	14.32
VDT6224	H-60A/L FORE	1034	19.49	929	18.13
VDT6226	Glatz*	2676	24.34	952	x
VDT6227	UH-60M	1481	28.56	1346	19.69

*seat broke, seat pan accelerometers under seat cushion

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Table 13 gives the neck injury results for Cell C. Cells shown in red exceeded the injury criteria. The Glatz seat failed the tension-flexion criteria, though this is expected as the seat broke and 'hung' the manikin during the impact. The H-60A/L seats as well as the UH-60M seat all passed the Nij criteria.

Table 13. CV Cell C LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6235	H-60A/L AFT	0.0000	0.0220	0.1227	0.1325	0.1325	0.11555	0.06972
VDT6224	H-60A/L FORE	0.1729	0.0523	0.0821	0.1543	0.1729	0.04573	0.01969
VDT6226	Glatz*	0.6815	0.4056	0.0224	0.1859	0.6815	0.25397	0.10259
VDT6227	UH-60M	0.2913	0.2840	0.1231	0.1743	0.2913	0.11934	0.05581

*seat structural failure

Table 14 summarizes the injury results of Cell D (36.35G, 48.89 ft/s). Neither the Wolf nor Glatz seats were tested during this Cell given the structural issues during Cells A, B, and C. The seat pan accelerometers along with the chest Z accelerometer did not collect good data during test VDT6228. In comparing peak lumbar Z force, both H-60A/L fore and Aft facing seats were considerably lower than the UH-60M seat. However, all peak lumbar Z forces are lower than the 2235 lb lumbar force limit.

Table 14. CV Cell D LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6236	H-60A/L AFT	77	58.13	632	18.66
VDT6225	H-60A/L FORE	1182	36.54	778	x
VDT6228	UH-60M	1830	x	1284	x

Table 15 summarizes the neck injury probability results for Cell D. Cells shown in red have exceeded the injury criteria. Both the H-60A/L forward-facing and UH-60M seats exceeded the Nij.

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Table 15. CV Cell D LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6236	H-60A/L AFT	0.1148	0.0561	0.3732	0.0537	0.3732	0.19797	0.10581
VDT6225	H-60A/L FORE	0.1601	0.7602	0.0946	0.2087	0.7602	0.07309	0.05485
VDT6228	UH-60M	0.5248	0.4601	0.1345	0.1734	0.5248	0.21492	0.06803

The H-60A/L Aft facing seat consistently performed well compared to the other seats in the CV orientation. Peak lumbar Z forces were consistently lower than the forward-facing seats. Also, the aft-facing seat did not exceed the neck injury criteria in this orientation. For the LOIS tests, the forward-facing seats exceeded the lumbar force injury criteria while the aft-facing seat did not. Peak torso restraint forces in general were not exceeded in the CV orientation.

6.2 Pure Vertical Tests

Nij, peak lumbar Z force, peak chest acceleration resultant, peak torso belt force, DRZ, and Eiband are reported for the Pure Vertical orientation.

Table 16 summarizes the injury metrics for Cell G. Cells shown in red have exceeded the injury criteria. As the acceleration levels for Cell G were close to the minimum levels needed to stroke, most of the seat configurations were tested a second time at higher impact levels to ensure stroking occurred. As the Glatz seat does not stroke, only one Glatz seat test was needed in this Cell. For the Glatz CV testing the seat pan accelerometers were placed under the seat cushion. For the PV tests, the seat pan accelerometers were placed on top of the seat cushion directly underneath the manikin, allowing for direct comparison to the other seats. All peak torso belt forces were within the 2000 lb limit. The peak lumbar Z force for the UH-60M seat was consistently higher than the other seats (VDT6237 and VDT6238). Even though the Wolf seat did not stroke for either Cell G tests (VDT6242 and VDT6243), the peak lumbar Z forces were still lower than the UH-60M seat. Both the UH-60M and Wolf seat tests exceeded the lumbar force criteria of 963 lb force.

Table 16. PV Cell G LOIS Injury Comparison Results

Test #	Seat	Acceleration (G's)	Velocity Change (ft/s)	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6245	H-60A/L FORE*	14.87	35.3	91	19.31	760	22.86
VDT6246	H-60A/L FORE	16.55	34.1	170	23.23	902	24.57

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VDT6253	Glatz	16.92	35	129	26.22	939	29.89
VDT6237	UH-60M*	13.91	36	99	28.79	1207	22.42
VDT6238	UH-60M	15.52	35.4	110	33.05	1385	25.15
VDT6242	Wolf*	14.79	35.1	213	24.67	986	26.47
VDT6243	Wolf*	16.78	34.3	235	25.08	1010	28.71

*no seat stroke

Figure 10 is a logarithmic graph of the seat pan acceleration Z versus the duration with the Eiband criteria. Eiband is typically a discrete point; however, since the pulses used are sinusoidal instead of trapezoidal, Eiband is graphed as continuous. All seats had short duration accelerations within the “Area of Moderate Injury”, which may include extremity, skull, or lumbar fractures.

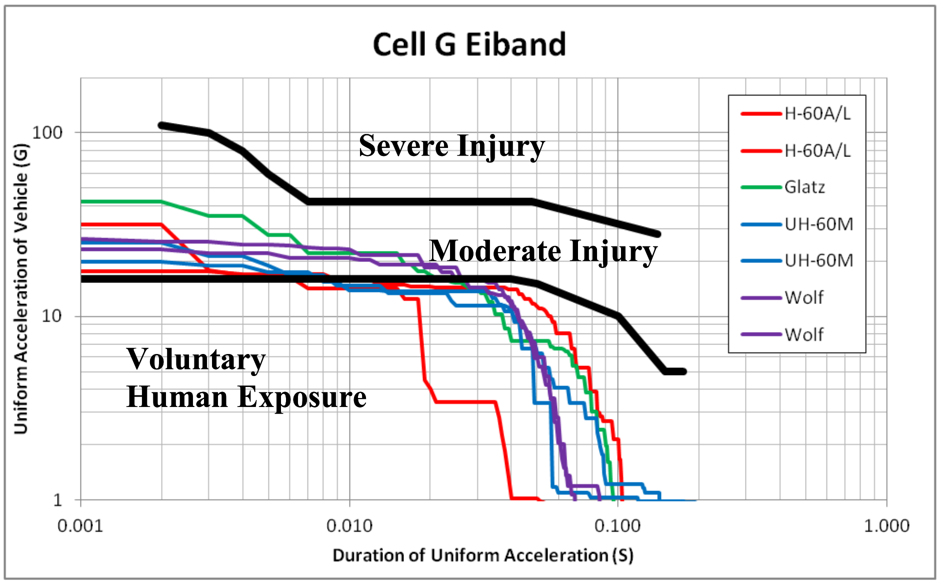

Figure 10. Cell G Continuous Eiband Plots

Table 17 summarizes the neck injury results of the Cell G tests. Cells shown in red have exceeded the injury criteria. The second UH-60M test (VDT6238) barely exceeded the compression-flexion criteria. The Glatz and Wolf tests were just under the limit of 0.5.

Table 17. PV Cell G LOIS Neck Injury Comparison Results

Test #	Seat	Acceleration (G's)	Velocity Change (ft/s)	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6245	H-60A/L FORE*	14.87	35.3	0.0582	0.0795	0.2537	0.1191	0.2537	0.06727	0.03462

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VDT6246	H-60A/L FORE	16.55	34.1	0.0581	0.1130	0.2969	0.2326	0.2969	0.11503	0.04149
VDT6253	Glatz	16.92	35	0.1084	0.0956	0.4998	0.2613	0.4998	0.10143	0.02938
VDT6237	UH-60M*	13.91	36	0.0000	0.0000	0.4106	0.3395	0.4106	0.03329	0.02729
VDT6238	UH-60M	15.52	35.4	0.0370	0.1003	0.5505	0.3891	0.5505	0.03945	0.01714
VDT6242	Wolf*	14.79	35.1	0.2181	0.0863	0.4802	0.2031	0.4802	0.05331	0.03482
VDT6243	Wolf*	16.78	34.3	0.2168	0.2151	0.4565	0.1918	0.4565	0.03083	0.02169

*no seat stroke

Table 18 summarizes the injury results for Cell H (33.83G, 46.24 ft/s). Cells shown in red exceeded the injury criteria. All restraint belt forces were within established injury criteria. The Glatz seat had a very high chest resultant acceleration of 53.99G. During the first Wolf test, the seat did not stroke. Engineers from Wolf Technical Services replaced the brake compound to see if the seat would stroke. After the modification the seat was able to stroke (VDT6248) and lumbar forces were in the range of the other seats at this acceleration and velocity level. All seats exceeded the LOIS lumbar force criteria of 963 lb force. Similarly, all DRZs were greater than 50% probability of lumbar injury.

Table 18. PV Cell H LOIS Injury Comparison Results

Test #	**Seat**	**Torso Belts Peak Force (lb)**	**Chest Resultant G**	**Peak Lumbar Z Force (lb)**	**DRZ**
VDT6247	H-60A/L FORE	136	31.03	1104	34.96
VDT6254	Glatz	277	53.99	1360	47.88
VDT6239	UH-60M	145	31.62	1186	33.24
VDT6244	Wolf*	308	41.64	1569	44.24
VDT6248	Wolf**	243	35.72	1068	39.36

*seat did not stroke
**modified Wolf seat

Figure 11 shows continuous Eiband for each seat test for Cell H. All seats were within "Area of Moderate Injury", which may include extremity, skull, or lumbar fractures.

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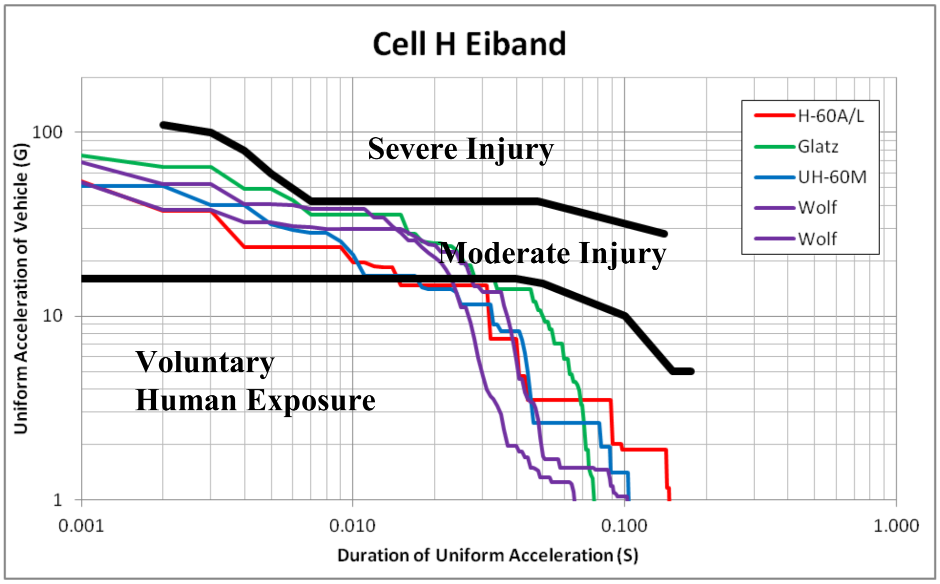

Figure 11. Cell H Continuous Eiband Plots

Table 19 summarizes the neck injury criteria for Cell H. Cells shown in red have exceeded the injury criteria. All seats exceed at least one Nij criteria. The modified Wolf seat had the highest exceedance with 1.2084 in tension-extension.Of the seats that performed correctly, the Glatz seat had the highest probability of neck injury compared to the other seats.

Table 19. PV Cell H LOIS Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6247	H-60A/L FORE	0.1859	0.5763	0.3305	0.0958	0.5763	0.08383	0.02432
VDT6254	Glatz	0.2188	1.0350	0.5235	0.5865	1.0350	0.17303	0.04058
VDT6239	UH-60M	0.1017	0.0510	0.5231	0.5251	0.5251	0.04474	0.03183
VDT6244*	Wolf*	0.4801	1.2084	0.3135	0.2756	1.2084	0.20340	0.04652
VDT6248	Wolf**	0.1460	1.2130	0.3276	0.2364	1.2130	0.41172	0.07364

*seat did not stroke
**modified Wolf seat

Table 20 summarizes the injury criteria for Cell I (16G, 31ft/s, 35ms rise time). All restraint forces as well as peak lumbar Z forces were within the peak lumbar force injury criteria. The H-60A/L forward-facing seat had the lowest chest resultant G of 18.61G. DRZ for the H-60A/L and Glatz seats are below 5% probability of spinal injury while the UH-60M is ~50% probability of lumbar injury.

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Table 20. PV Cell I LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6251	H-60A/L FORE	129	18.61	1162	16.42
VDT6255	Glatz	415	26.19	897	12.42
VDT6240	UH-60M	229	25.99	1504	22.47

Figure 12 graphs continuous Eiband criteria for each seat test in Cell I. Both the H-60A/L and UH-60M are within the "Area of Moderate Injury", which may include extremity, skull, or lumbar fractures. The Glatz seat is the only seat that was within the "area of voluntary human exposure." This was consistent with the calculated DRZ.

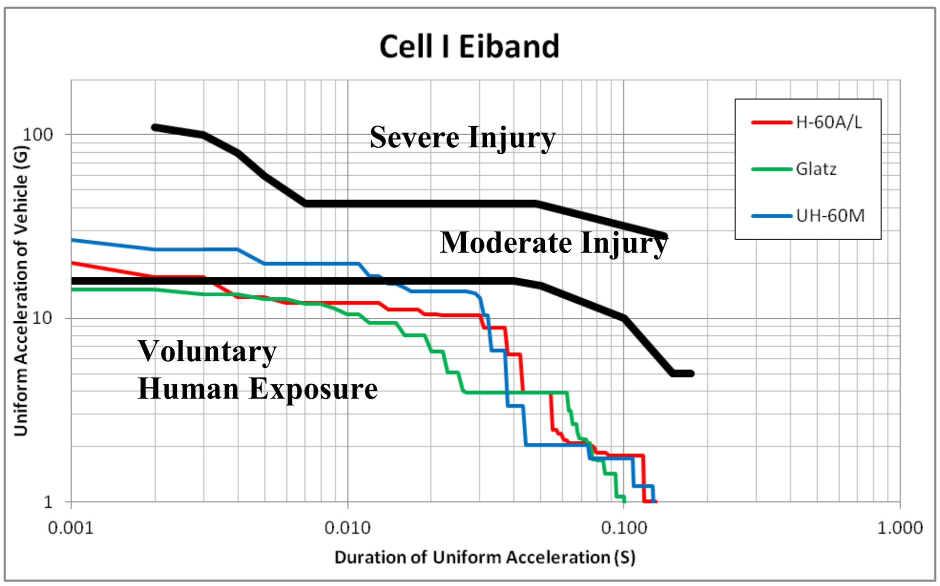

Figure 12. Cell I Continuous Eiband Plots

Table 21 summarizes the neck injury criteria for Cell I. All neck forces were within the LARD Nij injury criteria.

Table 21. PV Cell I LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6251	H-60A/L FORE	0.0063	0.0236	0.1232	0.1708	0.1708	0.01904	0.02284

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VDT6255	Glatz	0.0149	0.0318	0.1318	0.2839	0.2839	0.02967	0.01870
VDT6240	UH-60M	0.0750	0.0540	0.1296	0.1868	0.1868	0.02332	0.02043

To ensure the Wolf seat stroked, a higher nominal peak acceleration was planned for VDT6249 and designated I2. The impact pulse was 21.51G, 36.3 ft/s, with a 31.3ms rise time. The injury criteria results are summarized in Table 22. Peak torso belt forces and peak lumbar Z force were within the established injury criteria.

Table 22. PV Cell I2 Wolf Seat LARD Injury Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6249	Wolf	452	24.83	1449	26.3

Figure 13 graphs continuous Eiband for Cell I2. The Wolf seat accelerations are within the "Area of Moderate Injury", which may include extremity, skull, or lumbar fractures and is consistent with the DRZ of 26.3.

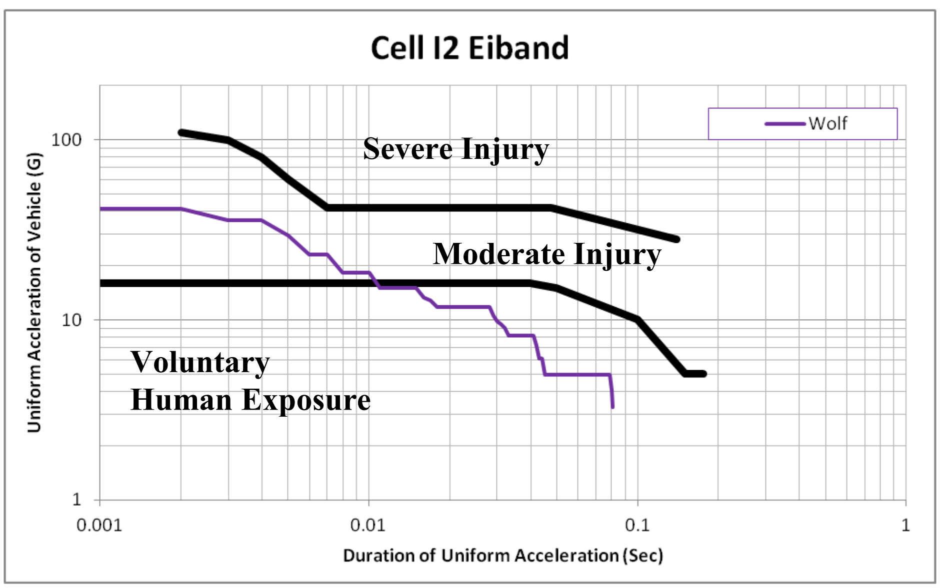

Figure 13. Cell I2 Continuous Eiband Plots

Table 23 summaries the neck injury results for VDT6249. All neck data passed the injury criteria.

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Table 23. PV Cell I2 LARD Wolf Seat Neck Injury Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6249	Wolf	0.1027	0.0773	0.2307	0.2152	0.2307	0.02879	0.01603

Table 24 summaries the injury criteria for Cell J (34.89G, 46.93 ft/s, 26.43ms rise time). Both the Wolf and Glatz seats included the brake and structural modifications, respectfully. VDT6256 did not use the lap restraint force cells due to unavailable space in the seat. Peak torso belt forces were within the 2000 lb limit. All peak lumbar Z forces were within the lumbar force criteria of 2235 lbs, though the H-60A/L forward-facing seat had the highest peak force of 1752 lbs. The Glatz seat had the lowest lumbar Z force of 1251 lbs. All seats, except the Glatz seat, had DRZs that correspond to a greater than 50% probability of lumbar injury. The Glatz seat had a probability of lumbar injury that corresponds to an approximate 5% probability of lumbar injury.

Table 24. PV Cell J LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z Force (lb)	DRZ
VDT6252	H-60A/L FORE	190	45.19	1752	23.79
VDT6256	Glatz**	493	44.34	1251	18.66
VDT6241	UH-60M	167	46.6	1421	31.69
VDT6250	Wolf*	280	25.28	1462	26.35

*Modified Wolf seat

**Modified Glatz seat

Figure 14 graphs continuous Eiband for all seats in Cell J. All seats were within the “Area of Moderate Injury”, which may include extremity, skull, or lumbar fractures.

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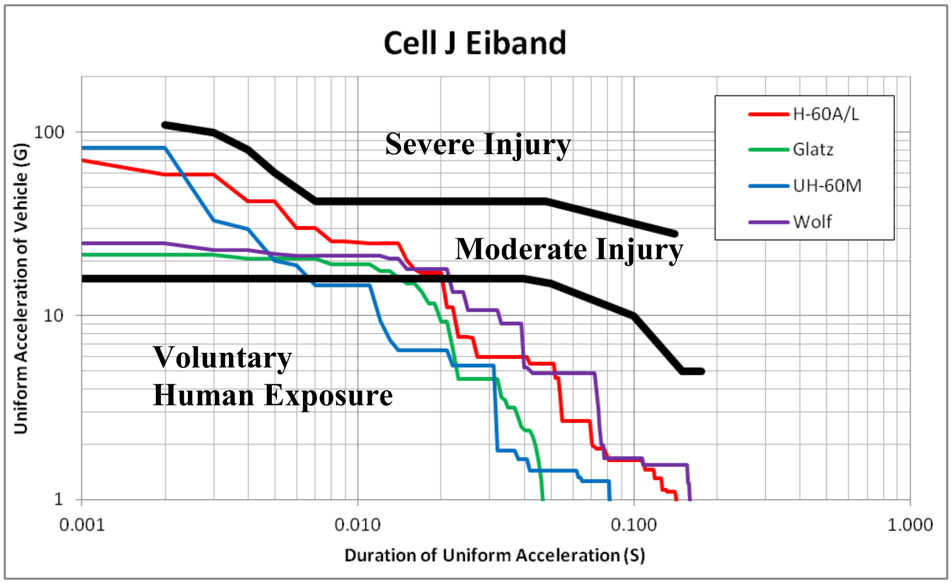

Figure 14. Cell J Continuous Eiband Plots

Table 25 summarizes the neck injury criteria for Cell J. All seats are within Nij LARD limits.

Table 25. PV Cell J LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
VDT6252	H-60A/L FORE	0.1160	0.1258	0.2269	0.1585	0.2269	0.04986	0.03354
VDT6256	Glatz**	0.0304	0.1092	0.1801	0.3890	0.3890	0.11963	0.03321
VDT6241	UH-60M	0.1751	0.1270	0.1276	0.4049	0.4049	0.04912	0.02169
VDT6250	Wolf*	0.1078	0.0674	0.2116	0.2122	0.2122	0.05949	0.02481

*Modified Wolf seat
**Modified Glatz seat

6.3 Combined Horizontal Test Discussion

The CH orientation is primarily conducted to test the structural strength of each seat. Peak chest acceleration resultant, peak torso belt forces, and Nij are reported for the CH orientation.

Table 26 summarizes the injury results of Cell E (17.71G, 45.71 ft/s, 77.83ms rise time). As the manikin was pushed into the seat during the H-60A/L aft-facing test (HIA8516), the belt forces were not relevant or comparable to the other tests. The Glatz, Wolf, and H-60A/L aft-facing seats had structural failures during the test. The UH-60M seat structurally passed (HIA8511).

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The H-60A/L forward-facing seat (HIA8507) had the lowest belt forces. This is probably due to the seat 'stroking' as it swung horizontally during impact.

Table 26. CH Cell E LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G
HIA8507	H-60A/L FORE	1411	28.49
HIA8516	H-60A/L AFT	X	35.56
HIA8508	Glatz**	1815	20.23
HIA8510	Glatz*,**	X	24.17
HIA8511	UH-60M	1447	26.89
HIA8509	Wolf*	1647	28.25

*modified seats
**structural failure

Table 27 summarizes the neck injury criteria of Cell E. Cells shown in red have exceeded the injury criteria. The Glatz seat experienced structural failure during impact, thus the failure in neck injury criteria was expected.

Table 27. CH Cell E LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
HIA8507	H-60A/L FORE	0.1399	0.1511	0.0649	0.2113	0.2113	0.15345	0.05751
HIA8516	H-60A/L AFT	0.0819	0.2147	0.4213	0.0474	0.4213	0.26889	0.14865
HIA8508	Glatz**	0.4388	0.8389	0.0455	0.0944	0.8389	0.21604	0.16790
HIA8510	Glatz*,**	0.6515	0.3593	0.8480	0.0869	0.8480	0.24222	0.07703
HIA8511	UH-60M	0.1539	0.2963	0.0596	0.0182	0.2963	0.13188	0.05532
HIA8509	Wolf*	0.0889	0.2212	0.0858	0.0945	0.2212	0.18922	0.10436

*Modified seats
**structural failure

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Only the UH-60M seat was tested at the Cell F conditions (24.15G, 52.85 ft/s, 62ms rise time) given the structural failures of the H-60A/L aft-facing, Glatz, and Wolf seats at the lower acceleration level.

Table 28 summarizes the injury criteria for the UH-60M seat test for Cell F. Cells shown in red have exceeded the injury criteria. The seat experienced structural failure of the lower mounts during the impact, allowing the seat and manikin to swing upwards on the top mounts. Peak torso belt force criteria were exceeded.

Table 28. CH Cell F LARD Injury Comparison Results

Test #	Seat	Torso Belts Peak Force (lb)	Chest Resultant G
HIA8515	UH-60M	2838	35.37

Table 29 summarizes the neck injury results for Cell F. No LARD neck injury criteria were exceeded.

Table 29. CH Cell F LARD Neck Injury Comparison Results

Test #	Seat	Ntf	Nte	Ncf	Nce	Composite Nij	UNMIx	UNMIz
HIA8515	UH-60M	0.1369	0.4086	0.6414	0.5705	0.6414	0.27632	0.05479

6.4 General Observations

As the H-60A/L seat is the legacy seat currently used in most H-60 rotorcraft, the other seats can be compared to this seat. The H-60A/L aft-facing seat consistently generated lower peak lumbar Z forces during CV and PV LOIS tests. This seat also consistently passed the neck injury criteria even though it did have a structural failure during the CH test. The seat also performed well in CV and PV orientations with LARD at the different energy levels. During the single CH test, the right energy attenuator wire snapped during impact.

The H-60A/L forward-facing seat did not experience any significant structural failure during testing. Peak lumbar forces during LOIS CV testing exceeded lumbar force criteria, though this value may be within the expected noise in the test setup. The seat did experience a Nij tension-extension failure, though all seats experienced tension-extension failures at both energy levels

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tested. The seat performed well during LARD CV with only a Nij tension-extension exceedance at the higher energy level. Peak lumbar force criteria were exceeded during the high-energy PV LOIS test, though all seats failed the same criteria. DRZ was consistently high for both CV and PV testing, and the seat pan accelerations were within the "Area of Moderate Injury" when compared to the Eiband criteria. Similarly, all seats failed Nij tension-extension at the higher level. During CH testing, the H-60A/L forward-facing did not have any structural failures at the lower energy level. However, the seat was not tested at the higher level given how far the seat stroked at the lower energy level.

The UH-60M seat structurally performed well during all tests. The only test where the seat had major structural damage was at a level that no other seat was tested at, Cell F. Lumbar forces for the UH-60M seat appear to be slightly higher than the H-60A/L seats as well as the prototype seats. However, lumbar force criteria failure was consistent with the other seats tested.

The Glatz seat experienced structural failure during multiple tests. With modifications to the seat, the seat performed better in some conditions, though structural failure during both CH tests shows that further redesign is required. Lumbar forces were generally consistent with the other seats. However, the Glatz seat has a higher probability of neck injury than the other properly-working seats during PV testing. The Glatz seat was the only seat that passed the Eiband criteria in Cell I.

The Wolf seat had many structural and functional issues, making comparison to the other seats difficult. When modifications to the seat structure and braking mechanism were made, lumbar forces were consistent with the other seats.

All seats performed well with the large occupant compared to the injury criteria. However, all seats show deficiencies when used with a small occupant. It is understood that the H-60A/L and UH-60M seats were not designed with consideration of the small female occupant; therefore, a higher probability of injury for small occupants would not be unexpected. This probability of injury should be documented, although any statement should consider the low probability of a small occupant without any additional gear using any of these seats.

6.5 Comparison to Operational Mishap Data

The Mapes et al (2008) study presented a clear picture of the locations of major and fatal injuries that have occurred during Class A and B mishaps. Laboratory tests are not intended to match specific operational crash conditions. Instead, combining the knowledge of operational injuries documented during mishaps as well as relative seat performance in the laboratory allows for comparison of newer and prototype seats to legacy seats. Mapes et al showed that head, chest, spine, and lower extremity major and fatal injuries occurred in both human-factor and non-human factor mishaps (Figures 15 and 16). Barth (2009) and Labun (2009) injury distributions also generally agree with the Mapes analysis. The operational mishap data shows which criteria are most important in comparing seats. Laboratory testing does not allow for head injury prediction during the seat stroking event as the surrounding aircraft and equipment environment is not modeled. However, chest, spine, and neck injury probability can be compared among the seats tested using the legacy H-60A/L seat as a baseline. Since the intent of testing is comparative, only statements of 'better' or 'worse' than the H-60A/L seat can reasonably be made. How much 'better' or 'worse' in respect to anticipated operational mishap data cannot be determined other than comparison to established injury criteria.

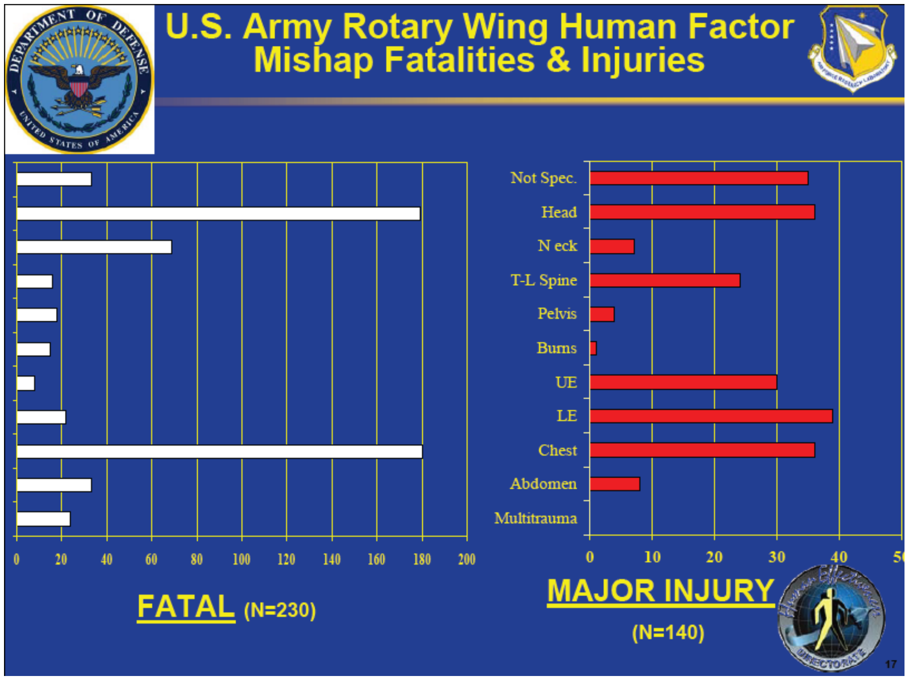

Figure 15. Army Human Factor Mishap Injuries

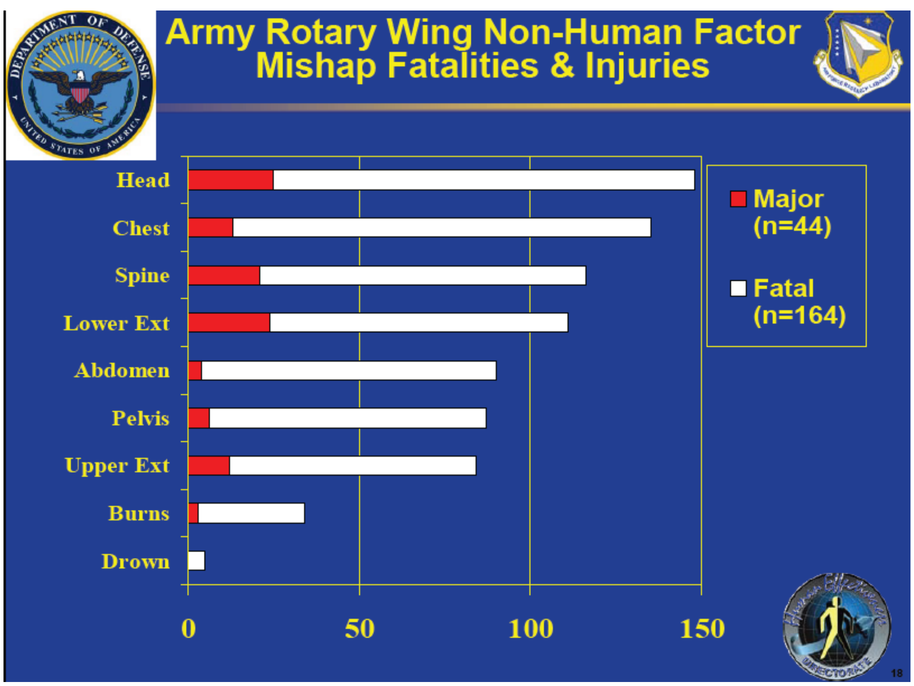

Figure 16. Army Non-Human Mishap Injuries

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The first comparison is whether the seat structurally survived the impact. If a seat broke or did not hold the occupant within the nominally survivable space, injuries beyond the scope of this program including head and other blunt impact are likely. The H-60A/L seat performed generally well structurally. It is noted that the top attachment hooks could become unattached as the seat rebounded post-impact. It is recommended that these hooks be wrapped with something to prevent post-impact release of the seat and man into the cabin and/or outside the rotorcraft. The H-60A/L aft-facing seat had a failure of one of the top energy attenuators during the CH test, which would have allowed the occupant to be free within the cabin post-impact. Of note only the UH-60M was tested at the higher CH energy level due to either structural failure of the Glatz and Wolf seats at the lower energy level or the anticipation of failure of the H-60A/L seat at the higher level. The CH tests, at both low and high energy levels, show that all the seats require additional structural support. This is also evident in the structural failures of the Wolf and Glatz seats during the CV and PV testing. Even with structural failures during some tests, seat performance can be compared in many of the Cells tested.

In plotting the performance of the legacy H-60A/L seats' laboratory test data relative to the Eiband criteria, it is not surprising that the expected type and severity of injuries would be similar to the operational mishap data. Given how all the other seats performed and were almost exclusively in the 'moderate' range of injury, it would be expected that similar levels and severities of injuries would also be seen in the UH-60M, Glatz, and Wolf seats.

Barth (2009) showed that major or fatal thoracic organ injuries, primarily the heart, aorta, and lungs, are not independent of head and spine injury. Thoracic injuries, therefore, should be considered by looking at both the peak lumbar Z forces measured during impact as well as chest acceleration. Peak chest acceleration resultant was chosen instead of torso belt load as a basis of comparison for two reasons; first, vascular injury is primarily acceleration-dependent and, second, chest acceleration resultants from both CV and PV tests are more easily compared than torso belt loads. Peak lumbar Z force and resultant chest acceleration were ranked for the Cells where direct comparison of seats was possible. Peak values were rated from lowest to highest. A rating of 1 means that it had the lowest peak value, and a rating of 5 means it had the highest peak value. Of note the data on the Wolf seat are most limited given the structural and functional problems with the seats. However, the data are still reported in the below tables.

Table 30 ranks LOIS peak lumbar Z force among the cells where direct comparison is possible. Cells in red show where the peak lumbar force criteria of 963 lb was exceeded. The H-60A/L aft- and forward-facing seats are essentially the same; thus the PV tests with the H-60A/L are the results for the aft-facing seat. Cell G is split into two columns: Cell G being the nominal acceleration level of 16.44 G while G1 is the initial acceleration where the seats were tested (14.5G) and the seats did not stroke. Also of note is that the Glatz seat was only tested at the 16.44G level. The H-60A/L aft- and forward-facing seats are the baseline in this comparison. Both the H-60A/L aft- and forward-facing seats generally have the lowest peak lumbar Z values and are rated the best. The Glatz seat had the next best average peak lumbar Z force. The Wolf seat in Cell H had the best peak lumbar Z force in Cell H. During Cell H the Wolf seat stroked as intended, unlike in the other Cells.

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Table 30. LOIS Peak Lumbar Force Z Rank

	Cell A (CV)	Cell B (CV)	Cell G (PV)	Cell G1 (PV)	Cell H (PV)	Average Rank
H-60A/L Aft	1	1	1	1	2	1.20
H-60A/L Fore	2	2	1	1	2	1.60
Glatz	3	*	3	N/A	5	3.67
UH-60M	4	3	5	4	4	4.00
Wolf	5	4	4	3	1	3.40

1 = best, 5 = worst
Red indicates the peak lumbar force criteria was exceeded
*structural failure of seat

Table 31 ranks the LOIS chest acceleration resultant for the seats where direct comparisons between the seats are possible. No seat exceeded the limit of 60 G. The results of the H-60A/L PV tests are again relevant for both the forward and aft facing seats. The H-60A/L seats had the lowest (best) chest accelerations of the seats tested. This is consistent, and expected with the lumbar load peak rankings. The Glatz seat had the highest (thus worst) average chest accelerations. The UH-60M and Wolf seats were similar in rank.

Table 31. LOIS Chest Acceleration Resultant Rank

	Cell A (CV)	Cell B (CV)	Cell G (PV)	Cell G1 (PV)	Cell H (PV)	Average Rank
H-60A/L Aft	1	2	1	1	1	1.20
H-60A/L Fore	2	1	1	1	1	1.20
Glatz	5	*	4	N/A	5	4.67
UH-60M	3	3	5	4	3	3.60
Wolf	4	4	3	3	4	3.60

1 = best, 5 = worst
*structural failure of seat

Table 32 ranks the LARD peak lumbar Z forces across Cells where direct comparison of data is possible. The H-60A/L seats are again the baseline. The H-60A/L seats had the lowest peak lumbar Z forces during the CV tests. The H-60A/L seats had the highest (worst) peak lumbar Z force during Cell J. This seat stroked 11.75” during impact, thus the load seen is of the seat and manikin bottoming out. Due to a structural failure of the Glatz seat during Cell C, the Glatz seat was not tested in Cell D. The Glatz seat performed well in both PV tests relative to the other seats. Lumbar loads were noticeably lower in the Glatz seat than the other seats. The Wolf seat was not tested in Cells C and D, and the seat was tested at a separate level than the other seats to

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ensure it would stroke (Cell I2). Because of limited data it is difficult to compare to the other seats. No LARD test exceeded the lumbar load limit of 2235 lb.

Table 32. LARD Peak Lumbar Force Z Rank

	Cell C (CV)	Cell D (CV)	Cell I (PV)	Cell J (PV)	Average Rank
H-60A/L Aft	1	1	2	4	2.00
H-60A/L Fore	2	2	2	4	2.50
Glatz	*	N/A	1	1	1.00
UH-60M	3	3	4	2	3.00
Wolf	N/A	N/A	N/A	3	3.00

1 = best, 5 = worst
*Seat structural failure

Table 33 ranks the LARD chest acceleration result across multiple cells. Of note is that the Wolf seat worked as anticipated after the braking material was replaced. However, any statistical analysis comparing the chest acceleration resultant is limited with only one test, though the test shows that the Wolf seat technology has promise as an energy attenuator. The H-60A/L aft-facing seat had a structural failure during Cell E. The H-60A/L forward-facing seat had the lowest (best) average rank of chest acceleration resultants.

Table 33. LARD Chest Acceleration Resultant Rank

	Cell C (CV)	Cell D (CV)	Cell E (CH)	Cell I (PV)	Cell J (PV)	Average Rank
H-60A/L Aft	3	2	*	1	3	2.25
H-60A/L Fore	1	1	2	1	3	1.60
Glatz	*	N/A	*	4	2	3.00
UH-60M	2	x	1	3	5	2.75
Wolf	N/A	N/A	*	N/A	1	1.00

1 = best, 5 = worst
*Structural failure of seat

Overall both peak lumbar Z force and chest acceleration resultants show that the legacy H-60A/L seats performed well when compared to the other seats tested. However, when the operational mishap data are considered, major and fatal injuries are still to be expected if all the seats were in operational use. Since head and impact injuries are the primary modes of major and fatal injuries, structural strength of the seat becomes one of the most important metrics in any of the seats tested. The UH-60M seat was shown to be one of the structurally strongest seats tested. The seat did not survive up to the acceleration and velocity levels that MIL-S-85510(AS) dictates, though the seat survived better than the other seats tested.

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7.0 CONCLUSION

A series of dynamic tests of both currently-used and prototype H-60 troop seats was performed to determine occupant protection during a crash event. The H-60A/L, UH-60M, prototype Glatz, and prototype Wolf seats were tested at several orientations including Combined Vertical, Pure Vertical and Combined Horizontal and at different acceleration and energy levels using small female and large male manikins. Acceleration, force, and moment biodynamic response data were compared to standard injury criteria recommended by the Full Spectrum Crashworthiness Report. The H-60A/L aft-facing seat generally demonstrated the highest level of protection of all the seats tested when solely looking at injury during seat stroke. This is most likely due to the orientation of the seat instead of any differences found within the seat itself when comparing the H-60A/L forward and aft-facing seat performance. For the CV tests, the manikin was forced into the seat instead of out of the seat with the H-60A/L aft-facing seat. The UH-60M seat demonstrated consistent structural strength compared to the H-60A/L and prototype seats. Both the Glatz and Wolf seats demonstrated structural failures that will require further redesign of the seats. All seats generated seat pan accelerations within the "Area of Moderate Injury" when using the Eiband criteria. Also, all seats had high DRZ values, showing a high probability of lumbar injury during the impacts. All seats performed well given a large occupant, though all seats showed deficiencies with respect to the criteria limits for a small occupant.

With deference to operational mishap data referenced by Mapes et al (2008), Barth (2009), and Labun (2009) relative comparison of the crashworthiness of the seats can be made to the legacy H-60A/L seat. The legacy H-60A/L seat generally performed better than the UH-60M, Glatz, and Wolf seats with respect to peak lumbar Z force and resultant chest acceleration. The high energy impact with LARD allowed the seat to fully stroke, showing that the limits of the energy attenuating system were exceeded. When considering Eiband criteria and comparisons to the operational mishap data, the same types and magnitudes of major and fatal injuries are anticipated with any of the seats tested.

Seat structural strength is the metric best defining the seats tested. The UH-60M was shown to be the strongest seat tested during the program. It is anticipated that head and other impact injuries shown in the operational mishap data would be mitigated if a seat stays attached to the aircraft and the occupant is not thrown about the cabin, although the level of mitigation would be demonstrated by the seat staying attached to the aircraft is unknown.

The testing and data analysis methodology developed during the program can be used to baseline and compare seats within a given aircraft platform or across different aircraft platforms. Combining quantitative injury criteria measures, such as those outlined within the FSC, along with laboratory and operational mishap data, allows new seats and seat technology to be quickly and inexpensively tested and compared with legacy seats. Additionally, legacy seats across multiple aircraft and rotorcraft platforms can be compared independent of aircraft structure.

8.0 RECOMMENDATIONS

- Provide a means to secure upper attachment hooks of legacy H-60A/L to prevent detachment during rebound of seat during impact.

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- Helmets should be used by all rotorcraft occupants during flight.
- All occupants of rotorcraft should be tightly restrained within a seat during flight.
- A stronger, structurally secure, passenger seat compared to the H-60A/L seat should be considered to potentially mitigate impact injuries following the initial crash pulse.
- The Wolf prototype seat shows promise in regards to an energy attenuation system. Execution of the technology was not optimal within the program.
- The Glatz prototype seat shows promise with respect to protection of an occupant during a crash event, though structural failures show redesign is necessary.
- Adopt FSC injury criteria to compare and acquire seats during rotorcraft and fixed-wing aircraft acquisition programs.
- Consider application of the methodology developed in this program to quickly and inexpensively compare occupant protection across different seats and aircraft platforms.
- Factors such as weight and cost of the seats were not considered during this program; since seat performance is shown to be similar across those seats tested, further analysis should be conducted on economic and weight gains of any new seat designs compared to the baseline.
- A study for base-lining impact injuries in aircraft with crashworthy seating should be completed.
- A study including a 50% male occupant manikin using the testing and data analysis methodology should be completed.

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ACRONYMS

711HPW	711th Human Performance Wing
ACH	Advanced Combat Helmet
AFRL	Air Force Research Laboratory
AIS	Abbreviated Injury Scale
CV	Combined Vertical
CH	Combined Horizontal
DOT&E	Office of the Director, Operational Test & Evaluation
DRI	Dynamic Response Index
DRMO	Defense Reutilization and Marketing Offices
DRZ	Dynamic Response Index Z
DSOC	Defense Safety Oversight Council
FSC	Full Spectrum Crashworthiness
HIA	Horizontal Impulse Accelerator
HIC	Head Injury Criterion
JSF	Joint Strike Fighter
LARD	Large Anthropomorphic Research Device
LOIS	Lightest Occupant In Service
MOA	Memorandum of Agreement
NIC	Neck Injury Criteria
OSD	Office of the Secretary of Defense
PV	Pure Vertical
SBIR	Small Business Innovative Research
UNMIx	Upper Neck Moment Index X
UNMIz	Upper Neck Moment Index Z
VDT	Vertical Deceleration Tower

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Appendix A. Injury Criteria Results

Test #	Cell	Orientation	Seat	Manikin	Acceleration (G's)	Velocity (fps)	Structure	Torso Belts Peak Force (lb)	Chest Resultant G	Peak Lumbar Z	DRZ	Eiband	Ntf	Nte	Ncf	Nce	UNMIx	UNMIz
VDT6219	A	CV	H-60A/L FORE	LOIS	23.76	38.58	YES	703	26.33	962	28.63	N/A	0.2612	0.5537	0.2941	0.1246	0.1881	0.1039
VDT6221	A	CV	Wolf	LOIS	23.2	38.67	NO	651	31.75	1518	33.44	N/A	0.0000	0.4299	0.6058	0.1228	0.1631	0.1186
VDT6222	A	CV	Glatz	LOIS	23.04	38.66	YES	700	40.66	1019	30.78	N/A	0.0500	0.6916	0.1308	0.4810	0.2047	0.0607
VDT6229	A	CV	UH-60M	LOIS	23.96	38.7	YES	804	31.74	1156	31.55	N/A	0.4581	0.5958	0.3498	0.4551	0.1734	0.0392
VDT6231	A	CV	Wolf	LOIS	22.94	38.75	YES	824	35.12	1396	36.89	N/A	0.3796	1.2354	0.4068	0.4490	0.2612	0.0733
VDT6233	A	CV	H-60A/L AFT	LOIS	23.23	38.56	YES	57	21.59	602	22.93	N/A	0.2069	0.1713	0.2836	0.2011	0.0949	0.0581
VDT6220	B	CV	H-60A/L FORE	LOIS	35.7	48.29	YES	1351	29.34	1103	32.06	N/A	0.0436	1.5822	0.2815	0.1653	0.2057	0.0747
VDT6223	B	CV	Glatz	LOIS	35.26	48.37	NO	1138	46.89	1153	39.47	N/A	0.7968	1.6599	0.1754	0.2770	0.4298	0.1381
VDT6230	B	CV	UH-60M	LOIS	34.39	48.4	YES	1073	48.26	1484	43.03	N/A	0.0615	1.8299	0.4782	0.4707	0.2853	0.0780
VDT6232	B	CV	Wolf	LOIS	35.24	48.33	YES	906	53.34	2032	51.39	N/A	0.0476	1.0310	0.7530	0.2848	0.3014	0.0411
VDT6234	B	CV	H-60A/L AFT	LOIS	34.13	48.17	YES	79	33.71	810	28.43	N/A	0.0940	0.1209	0.2825	0.0682	0.2095	0.0876
VDT6224	C	CV	H-60A/L FORE	LARD	25.47	40.51	YES	1034	19.49	929	18.13	N/A	0.1729	0.0523	0.0821	0.1543	0.0457	0.0197
VDT6226	C	CV	Glatz	LARD	25.82	40.48	NO	2676		952		N/A	0.6815	0.4056	0.0224	0.1859	0.2540	0.1026
VDT6227	C	CV	UH-60M	LARD	25.56	40.53	YES	1481	28.56	1346	19.69	N/A	0.2913	0.2840	0.1231	0.1743	0.1193	0.0558
VDT6235	C	CV	H-60A/L AFT	LARD	24.53	40.41	YES	71	28.9	564	14.32	N/A	0.0000	0.0220	0.1227	0.1325	0.1156	0.0697
VDT6225	D	CV	H-60A/L FORE	LARD	36.67	48.96	YES	1182	36.54	778		N/A	0.1601	0.7602	0.0946	0.2087	0.0731	0.0548
VDT6228	D	CV	UH-60M	LARD	36.49	39.85	YES	1830		1284		N/A	0.5248	0.4601	0.1345	0.1734	0.2149	0.0680
VDT6236	D	CV	H-60A/L AFT	LARD	35.9	48.82	YES	77	58.13	632	18.66	N/A	0.1148	0.0561	0.3732	0.0537	0.1980	0.1058
HIA8507	E	CH	H-60A/L FORE	LARD	17.74	45.66	YES	1411	28.49			N/A	0.1399	0.1511	0.0649	0.2113	0.1534	0.0575
HIA8508	E	CH	Glatz	LARD	18.05	46.15	NO	1815	20.23			N/A	0.4388	0.8389	0.0455	0.0944	0.2160	0.1679
HIA8509	E	CH	Wolf	LARD	17.58	45.97	NO	1647	28.25			N/A	0.0889	0.2212	0.0858	0.0945	0.1892	0.1044
HIA8510	E	CH	Glatz	LARD	18.15	45.83	NO		24.17			N/A	0.6515	0.3593	0.8480	0.0869	0.2422	0.0770
HIA8511	E	CH	UH-60M	LARD	17.28	45.17	YES	1447	26.89			N/A	0.1539	0.2963	0.0596	0.0182	0.1319	0.0553

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HIA8516	E	CH	H-60A/L AFT	LARD	17.47	45.48	NO		35.56			N/A	0.0819	0.2147	0.4213	0.0474	0.2689	0.1486
HIA8515	F	CH	UH-60M	LARD	24.15	52.85	NO	2838	35.37			N/A	0.1369	0.4086	0.6414	0.5705	0.2763	0.0548
VDT6238	G	PV	UH-60M	LOIS	15.52	30.89	YES	110	33.05	1385	25.15	Moderate	0.0370	0.1003	0.5505	0.3891	0.0394	0.0171
VDT6243	G	PV	Wolf	LOIS	16.78	31.82	YES	235	25.08	1010	28.71	Moderate	0.2168	0.2151	0.4565	0.1918	0.0308	0.0217
VDT6246	G	PV	H-60A/L FORE	LOIS	16.55	31.89	YES	170	23.23	902	24.57	Moderate	0.0581	0.1130	0.2969	0.2326	0.1150	0.0415
VDT6246X	G	PV	H-60A/L AFT	LOIS	16.55	31.89	YES	170	23.23	902	24.57	Moderate	0.0581	0.1130	0.2969	0.2326	0.1150	0.0415
VDT6253	G	PV	Glatz	LOIS	16.92	31.85	YES	129	26.22	939	29.89	Moderate	0.1084	0.0956	0.4998	0.2613	0.1014	0.0294
VDT6237	G1	PV	UH-60M	LOIS	13.91	28.83	YES	99	28.79	1207	22.42	Moderate	0.0000	0.0000	0.4106	0.3395	0.0333	0.0273
VDT6242	G1	PV	Wolf	LOIS	14.79	30.89	YES	213	24.67	986	26.47	Moderate	0.2181	0.0863	0.4802	0.2031	0.0533	0.0348
VDT6245	G1	PV	H-60A/L FORE	LOIS	14.87	30.83	YES	91	19.31	760	22.86	Moderate	0.0582	0.0795	0.2537	0.1191	0.0673	0.0346
VDT6245X	G1	PV	H-60A/L AFT	LOIS	14.87	30.83	YES	91	19.31	760	22.86	Moderate	0.0582	0.0795	0.2537	0.1191	0.0673	0.0346
VDT6239	H	PV	UH-60M	LOIS	33.41	46.19	YES	145	31.62	1186	33.24	Moderate	0.1017	0.0510	0.5231	0.5251	0.0447	0.0318
VDT6244	H	PV	Wolf	LOIS	34.24	46.29	YES	308	41.64	1569	44.24	Moderate	0.4801	1.2084	0.3135	0.2756	0.2034	0.0465
VDT6247	H	PV	H-60A/L FORE	LOIS	33.91	46.25	YES	136	31.03	1104	34.96	Moderate	0.1859	0.5763	0.3305	0.0958	0.0838	0.0243
VDT6247X	H	PV	H-60A/L AFT	LOIS	33.91	46.25	YES	136	31.03	1104	34.96	Moderate	0.1859	0.5763	0.3305	0.0958	0.0838	0.0243
VDT6248	H	PV	Wolf	LOIS	33.74	46.18	YES	243	35.72	1068	39.36	Moderate	0.1460	1.2130	0.3276	0.2364	0.4117	0.0736
VDT6254	H	PV	Glatz	LOIS	33.85	46.29	YES	277	53.99	1360	47.88	Moderate	0.2188	1.0350	0.5235	0.5865	0.1730	0.0406
VDT6240	I	PV	UH-60M	LARD	16.14	30.83	YES	229	25.99	1504	22.47	Moderate	0.0750	0.0540	0.1296	0.1868	0.0233	0.0204
VDT6251	I	PV	H-60A/L FORE	LARD	16.42	30.94	YES	129	18.61	1162	16.42	Moderate	0.0063	0.0236	0.1232	0.1708	0.0190	0.0228
VDT6251X	I	PV	H-60A/L AFT	LARD	16.42	30.94	YES	129	18.61	1162	16.42	Moderate	0.0063	0.0236	0.1232	0.1708	0.0190	0.0228
VDT6255	I	PV	Glatz	LARD	15.94	30.89	YES	415	26.19	897	12.42	Good	0.0149	0.0318	0.1318	0.2839	0.0297	0.0187
VDT6249	I2	PV	Wolf	LARD	21.51	36.3	YES	452	24.83	1449	26.29	Moderate	0.1027	0.0773	0.2307	0.2152	0.0288	0.0160
VDT6241	J	PV	UH-60M	LARD	34.91	46.98	YES	167	46.6	1421	31.69	Moderate	0.1751	0.1270	0.1276	0.4049	0.0491	0.0217
VDT6250	J	PV	Wolf	LARD	34.72	46.98	YES	280	25.28	1462	26.35	Moderate	0.1078	0.0674	0.2116	0.2122	0.0595	0.0248
VDT6252	J	PV	H-60A/L FORE	LARD	34.92	46.9	YES	190	45.19	1752	23.79	Moderate	0.1160	0.1258	0.2269	0.1585	0.0499	0.0335
VDT6252X	J	PV	H-60A/L AFT	LARD	34.92	46.9	YES	190	45.19	1752	23.79	Moderate	0.1160	0.1258	0.2269	0.1585	0.0499	0.0335
VDT6256	J	PV	Glatz	LARD	34.99	46.85	YES	493	44.34	1251	18.66	Moderate	0.0304	0.1092	0.1801	0.3890	0.1196	0.0332

Note: cells in red show structural failure or exceedances of criteria

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Appendix B. Structural Failure Summary

Test #	Cell	Orientation	Seat	Manikin	Structural Failure
VDT6219	A	CV	H-60A/L FORE	LOIS	Front right leg attachment detached
VDT6221	A	CV	Wolf	LOIS	Top right mount sheared through seat structure, and partial shearing of the left side mount. Feet broke during impact, Seat back was torn.
VDT6222	A	CV	Glatz	LOIS	The seat floor mount points deformed. The 1-inch webbing on seat back tore out of seat structure.
VDT6223	B	CV	Glatz	LOIS	Front right seat pan structure ripped and allowed cushion to submarine. Right lap restraint belt ripped from the seat structure. Seat attachment points deformed.
VDT6224	C	CV	H-60A/L FORE	LARD	Left upper attachment hook detached during seat rebound. The seat pan fabric ripped on the front tube.
VDT6225	D	CV	H-60A/L FORE	LARD	Seat pan fabric ripped from side to side.
VDT6226	C	CV	Glatz	LARD	Front right seat pan structure ripped. Both lap belts ripped from the seat.
VDT6227	C	CV	Martin Baker	LARD	Right foot disengaged from floor mount. Slight deformation of seat pan.
VDT6228	D	CV	Martin Baker	LARD	Vertical webbing on the side panel tore on the right side of the seat pan. Right foot of the seat detached from floor mount. Slight deformation in the seat pan.
VDT6229	A	CV	Martin Baker	LOIS	Slight deformation of the seat pan
VDT6230	B	CV	Martin Baker	LOIS	Slight deformation of the seat pan.
VDT6232	B	CV	Wolf	LOIS	Top hanger bent.
VDT6233	A	CV	H-60A/L AFT	LOIS	Manikin sunk into backpack pouch.
VDT6234	B	CV	H-60A/L AFT	LOIS	Manikin sunk into backpack pouch. Seat pan fabric ripped on the left side.
VDT6235	C	CV	H-60A/L AFT	LARD	Front right foot disengaged from floor mount. Seat pan fabric started to tear on both sides of the seat. Manikin sunk into backpack pouch.
VDT6236	D	CV	H-60A/L AFT	LARD	Tearing of the seat pan on both sides. Front left seat mount disengaged. Manikin sunk into backpack pouch.
VDT6240	I	PV	Martin Baker	LARD	Slight deformation in the seat pan.
VDT6241	J	PV	Martin Baker	LARD	Slight deformation of seat pan, bending in the seat pan rotation point.
VDT6244	H	PV	Wolf	LOIS	Seat pan fabric ripped, upper seat back fabric ripped.
VDT6246	G	PV	H-60A/L FORE	LOIS	Front of seat pan fabric ripped along seat pan frame.
VDT6247	H	PV	H-60A/L FORE	LOIS	Rear of the seat pan fabric ripped.
VDT6248	H	PV	Wolf	LOIS	Side of seat fabric ripped, top seat back fabric ripped.
VDT6249	I2	PV	Wolf	LARD	Rip in upper seat back fabric.
VDT6250	J	PV	Wolf	LARD	Upper seat back ripped, small tear at lower left side of seat back.
VDT6252	J	PV	H-60A/L FORE	LARD	Front left foot structurally failed and disengaged.

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VDT6254	H	PV	Glatz	LOIS	Cushion began to fall out of seat pan.
VDT6255	I	PV	Glatz	LARD	Cushion began to come out of seat pan, front right corner of seat pan started ripping, right lap belt started to rip out of the seat bucket.
VDT6256	J	PV	Glatz	LARD	Webbing to the front feet came loose, seat cushion started to come out of seat bucket, structural webbing on the right side panel ripped out of seat structure, back of the seat pan ripped, lap belts ripped out of the seat back, one tension rod at top of seat back broke.
HIA8507	E	CH	H-60A/L FORE	LARD	Cable from right back foot to left back seat pan broke.
HIA8508	E	CH	Glatz	LARD	Back webbing straps detached from seat structure, right lap belt ripped from seat structure, front right seat bucket tore, seat cushion disengaged from seat structure.
HIA8509	E	CH	Wolf	LARD	Right upper mount broke while the left showed signs of stretching, left foot detached from mount, seat structure broke along welds along top of seat.
HIA8510	E	CH	Glatz	LARD	Back webbing straps detached from seat structure, right lap belt ripped from seat structure, front right seat bucket tore, seat cushion disengaged from seat structure.
HIA8511	E	CH	Martin Baker	LARD	Slight deformation in seat pan.
HIA8515	F	CH	Martin Baker	LARD	Floor mounts broke, deformation in top mounts.
HIA8516	E	CH	H-60A/L FORE	LARD	Right upper wire bender and support cable from left foot to right seat pan broke.

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Appendix C. Individual Test Pictures

VDT6219 – Cell A, CV, H-60A/L forward-facing, LOIS, 23.76G, 38.58ft/s, 31ms rise time

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VDT6220 – Cell B, CV, H-60A/L Forward, LOIS, 35.7G, 48.29ft/s, 25.2ms rise time

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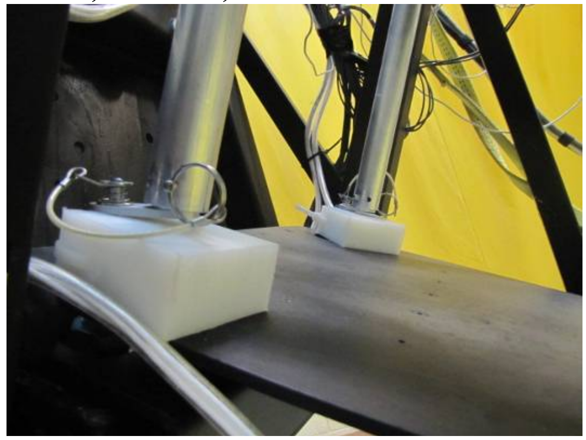
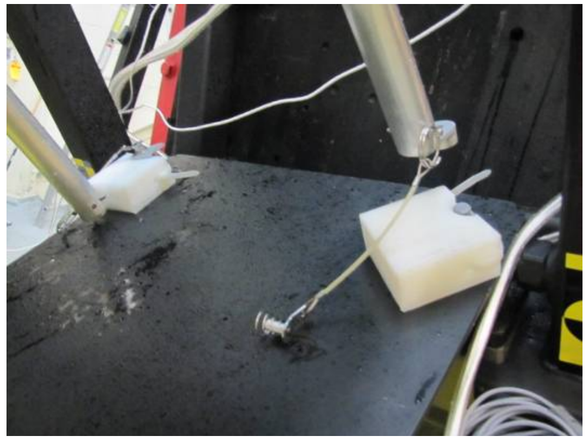
VDT6221 – Cell A, CV, Wolf, LOIS, 23.2G, 38.67ft/s, 31.2ms rise time





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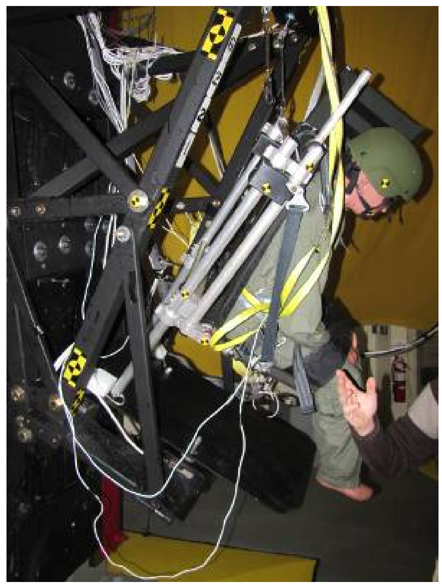

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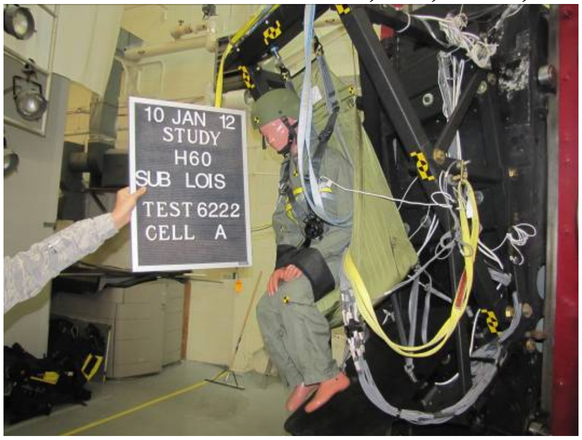
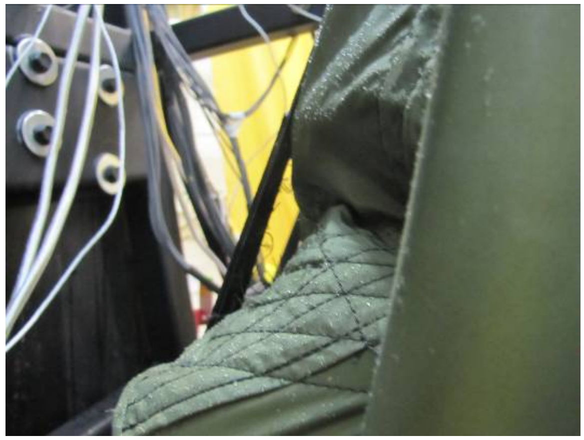
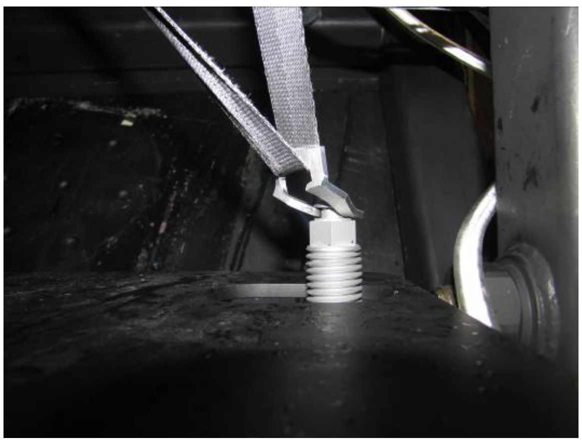
VDT6222 – Cell A, CV, Glatz, LOIS, 23.2G, 38.66ft/s, 29.6ms rise time







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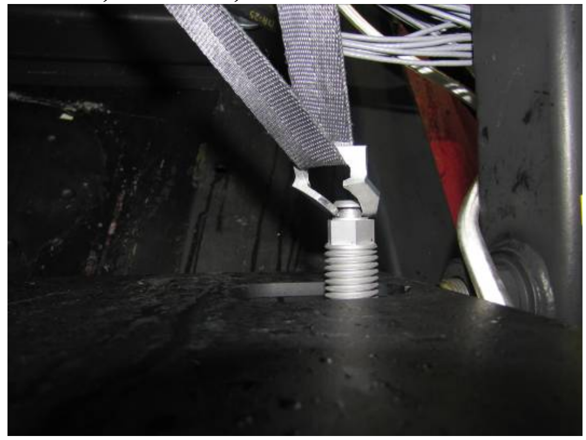
VDT6223 – Cell B, CV, Glatz, LOIS, 35.26G, 48.37ft/s, 25.4ms rise time



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VDT6224 – Cell C, CV, H-60A/L forward-facing, LARD, 25.47G, 40.51ft/s, 29.8ms rise time

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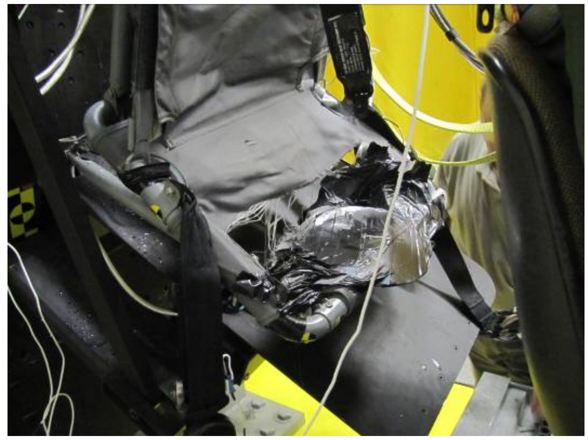
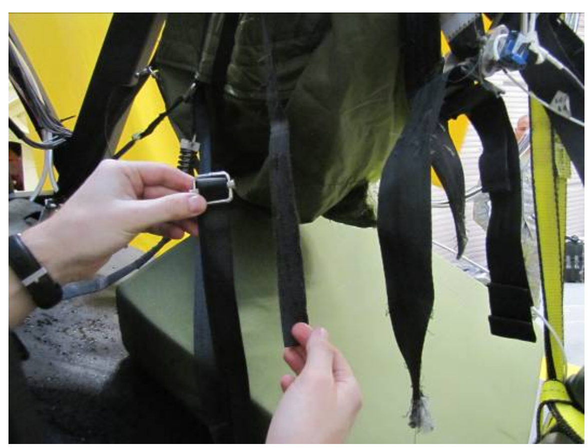
VDT6225 – Cell D, CV, H-60A/L forward-facing, LARD, 36.67G, 48.96ft/s, 24.7ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249



VDT6226 – Cell C, CV, Glatz, LARD, 25.82G, 40.48ft/s, 28.9ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

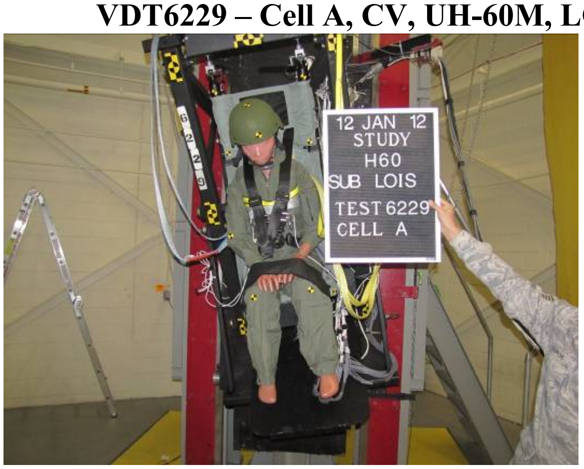
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6227 – Cell C, CV, UH-60M, LARD, 25.56G, 40.53ft/s, 29.1ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6228 – Cell D, CV, UH-60M, LARD, 36.49G, 39.85ft/s, 25.1ms rise time

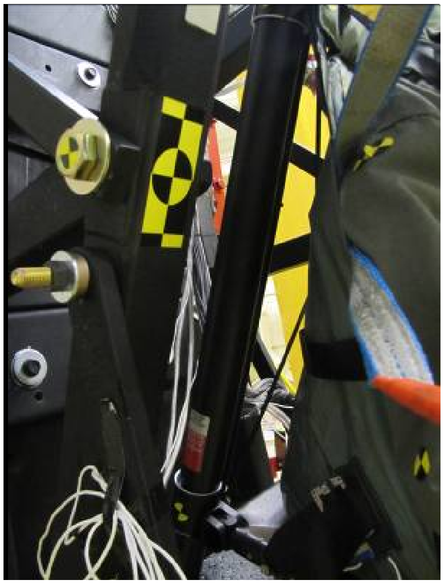
VDT6229 – Cell A, CV, UH-60M, LOIS, 23.96G, 38.7ft/s, 30.5ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6230 – Cell B, CV, UH-60M, LOIS, 34.39G, 48.40ft/s, 26.5ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

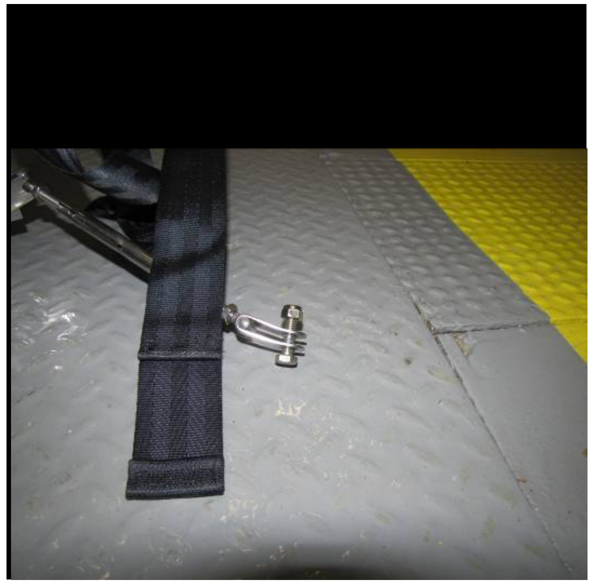


VDT6231 – Cell A, CV, Wolf, LOIS, 22.94G, 38.75ft/s, 30.3ms rise time

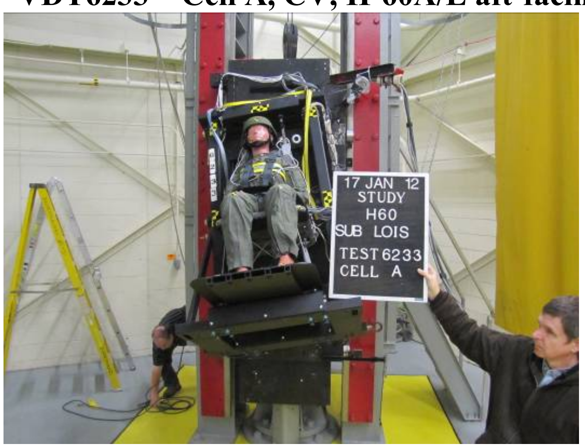
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6232 – Cell B, CV, Wolf, LOIS, 35.24G, 48.33ft/s, 25.7ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249



VDT6233 – Cell A, CV, H-60A/L aft-facing, LOIS, 23.23G, 38.56ft/s, 30.2ms rise time

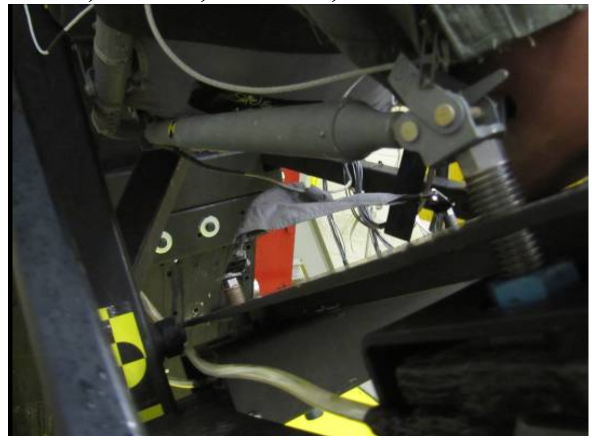


Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249




Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6234 – Cell B, CV, H-60A/L aft-facing, LOIS, 34.13G, 48.17ft/s, 26.3ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6235 – Cell C, CV, H-60A/L aft-facing, LARD, 24.53G, 40.41ft/s, 29.2ms rise time

VDT6236 – Cell D, CV, H-60A/L aft-facing, LARD, 35.90G, 48.82ft/s, 25.4ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT 6237 – Cell G, PV, UH-60M, LOIS, 13.91G, 28.83fts, 36ms rise time

VDT 6238 – Cell G, PV, UH-60M, LOIS, 15.52G, 30.89ft/s, 35.4ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT 6239 – Cell H, PV, UH-60M, LOIS, 33.41G, 46.19ft/s, 26ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

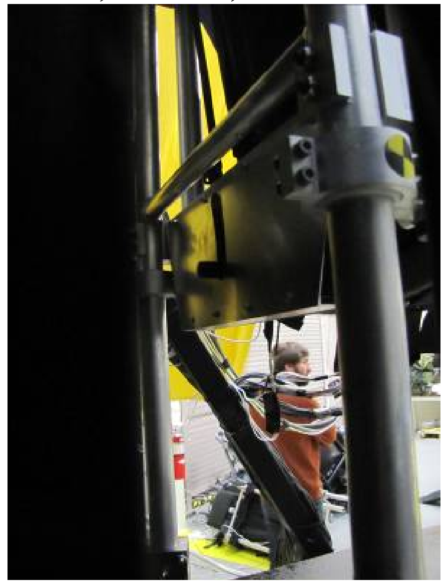
VDT6240 – Cell I, PV, UH-60M, LARD, 16.14G, 30.83ft/s, 35.7ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6241 – Cell J, PV, UH-60M, LARD, 34.91G, 46.98ft/s, 26.2ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

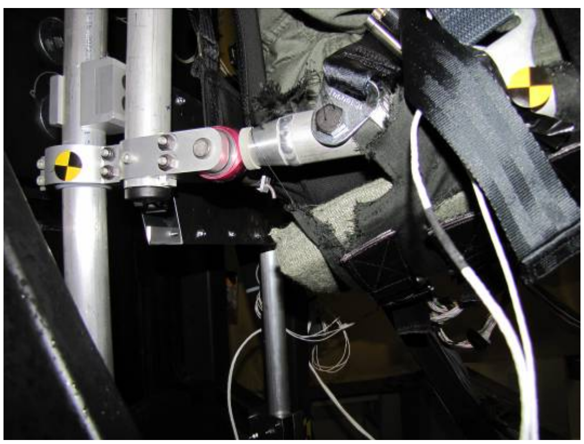
VDT6242 – Cell G, PV, Wolf, LOIS, 14.79G, 30.89ft/s, 35.1ms rise time

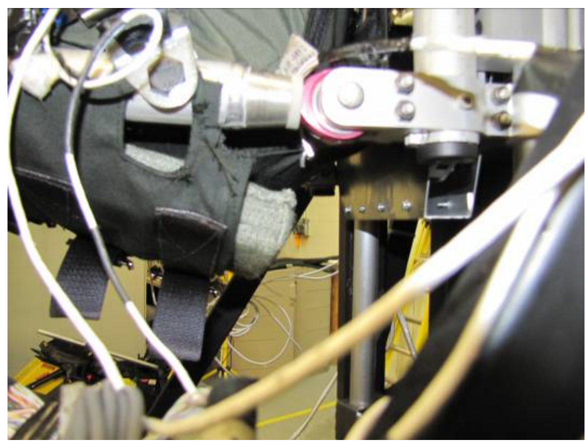


VDT6243 – Cell G, PV, Wolf, LOIS, 16.78G, 31.82ft/s, 34.3ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6244 – Cell H, PV, Wolf, LOIS, 34.24G, 46.29ft/s, 26.6ms rise time





Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6245 – Cell G, PV, H-60A/L forward-facing, LOIS, 14.87G, 30.83ft/s, 35.3ms rise time

VDT6246 – Cell G, PV, H-60A/L forward-facing, LOIS, 16.55G, 31.89ft/s, 34.1ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

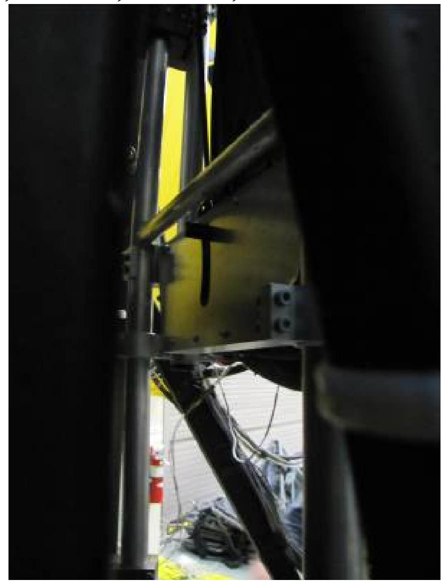
VDT6247 – Cell H, PV, H-60A/L forward-facing, LOIS, 33.91G, 46.25ft/s, 26.5ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6248 – Cell H, PV, Wolf, LOIS, 33.74G, 46.18ft/s, 26.6ms rise time

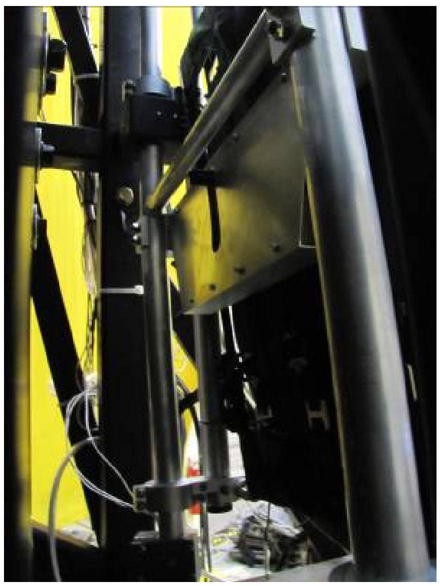
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6249 – Cell I2, PV, Wolf, LARD, 21.51G, 36.3ft/s, 31.3ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6250 – Cell J, PV, Wolf, LARD, 34.72G, 46.98ft/s, 26.7ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6251 – Cell I, PV, H-60A/L Forward-facing, LARD, 16.42G, 30.94ft/s, 35ms rise time

VDT6252 – Cell J, PV, H-60A/L Forward-facing, LARD, 34.92G, 46.9ft/s, 26.4ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

VDT6253 – Cell G, PV, Glatz, LOIS, 16.92G, 31.85ft/s, 35ms rise time

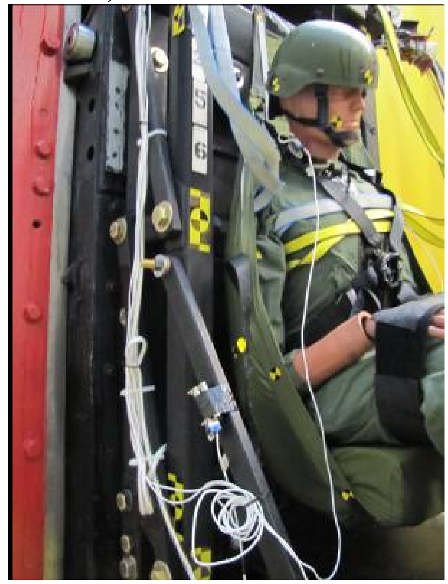
VDT6254 – Cell H, PV, Glatz, LOIS, 33.85G, 46.29ft/s, 26.2ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

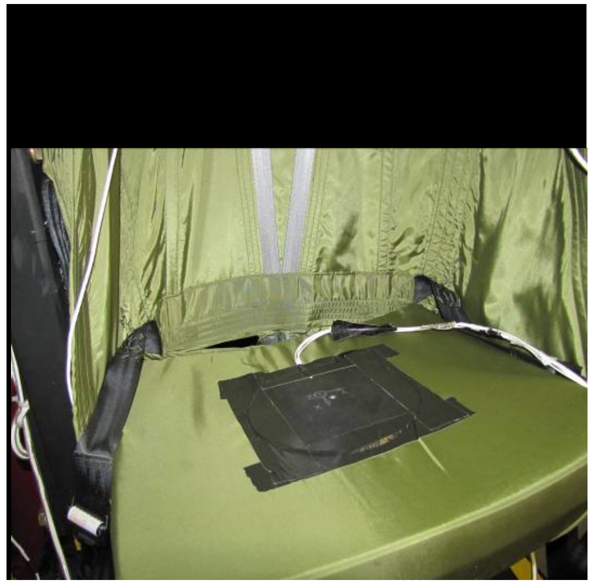
VDT6255 – Cell I, PV, Glatz, LARD, 15.94G, 30.89ft/s, 34.7ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

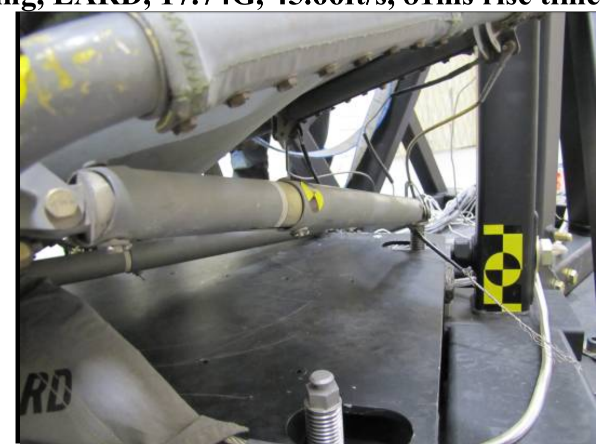
VDT6256 – Cell J, PV, Glatz, LARD, 34.99G, 46.85ft/s, 26.4ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249



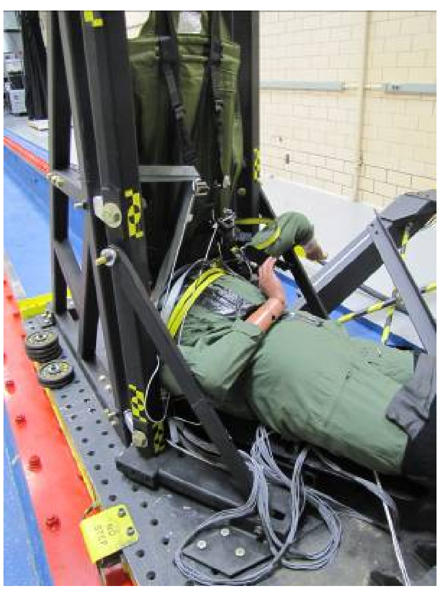
HIA8507 – Cell E, CH, H-60A/L Forward-facing, LARD, 17.74G, 45.66ft/s, 81ms rise time



Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

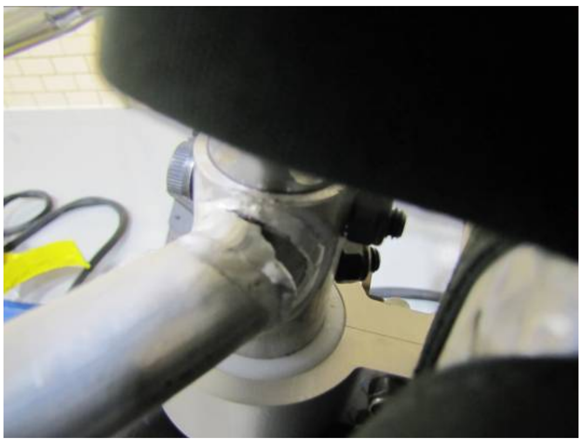
HIA8508 – Cell E, CH, Glatz, LARD, 18.05G 46.15ft/s, 71ms rise time

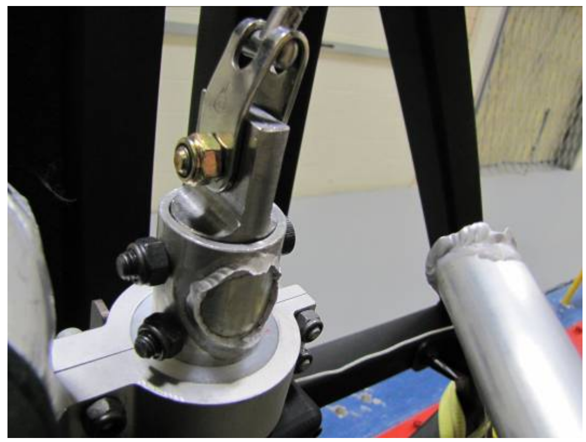
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

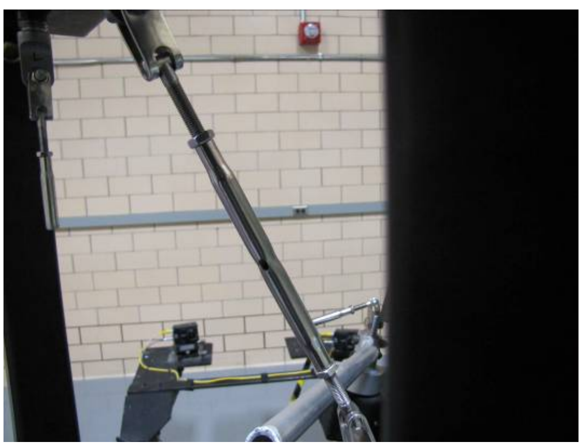


Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

HIA8509 – Cell E, CH, Wolf, LARD, 17.58G, 45.97ft/s, 81ms rise time

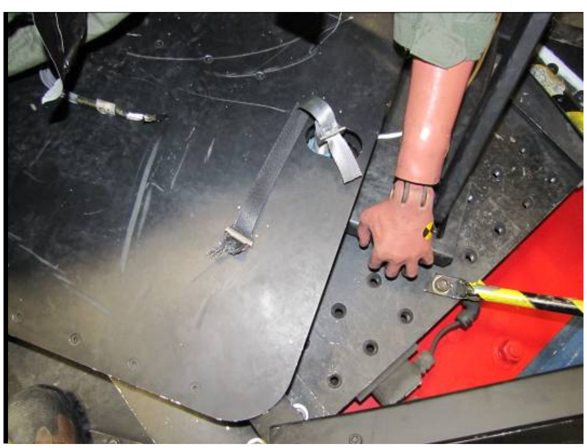






Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

HIA8510 – Cell E, CH, Glatz, LARD, 18.15G, 45.83ft/s, 72ms rise time



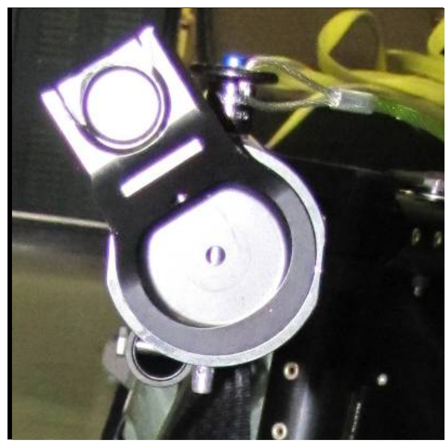
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

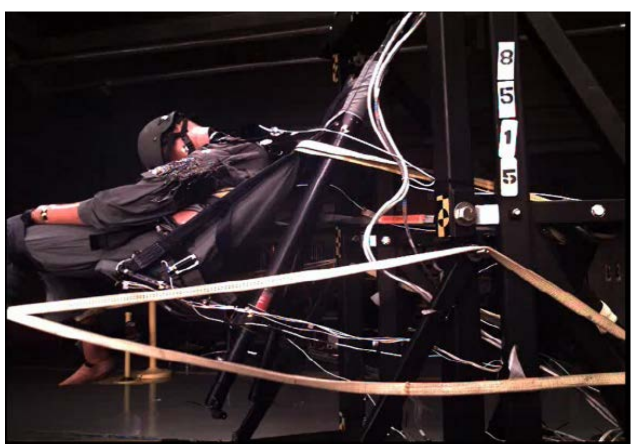
Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

HIA8511 – Cell E, CH, UH-60M, LARD, 17.28G, 45.17ft/s, 80ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

HIA8515 – Cell F, CH, UH-60M, LARD, 24.15G, 52.85ft/s, 62ms rise time





Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249

HIA8516 – Cell E, CH, H-60A/L Aft-facing, LARD, 17.47G, 45.48ft/s, 82ms rise time

Distribution A: Approved for public release; distribution unlimited.
88 ABW/PA Cleared 08/03/12; 88ABW-2012-4249